Article

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Developing the Framework of Drone Curriculum to Educate the Drone Beginners in the Korean Construction Industry

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Abstract: Both drones and laser scanners digitally take the as-built context of an object into the computer and the data taken is transmitted to a Building Information Modeling (BIM) world to create accurate 3D models. Although the laser scanner is the leading method of the Scan-to-BIM procedure, many professionals indicate drawbacks of the technology and point out the drone is an alternative that can improve the shortcomings, leading to the UAV-to-BIM process. Korean construction industry plans to implement the drone technology for scrutinizing as-built construction quality by 2025. However, the drone is *not* popular in the construction projects. Korean u*niversities where Construction Engineering and Management program have been implemented are requested to develop a drone curriculum for construction professionals.* Since the majority of the professionals are not familiar with drone operation, in order for the schools t*o be successful in developing the curriculum, it is very necessary to perform a* preliminary experimental study for identifying the essential education contents that are appropriate to drone beginners. The main objective of this paper is to perform the study for the drone beginners and recognize the recommendations and the framework of drone curriculum that will be beneficial for the schools to develop a comprehensive curriculum later on.

Keywords: drone; laser scanning; drone curriculum; construction operation monitoring; Smart Construction; Construction 4.0

1. Introduction

1.1. Research Background and Objective

The construction industry worldwide has been notorious for its negative features, i.e., numerous accidents and lower productivity and digitalization levels than other industries such as manufacturing and medicine. According to a McKinsey study, the industry suffers from a great deal of inefficiency; so to speak, large construction projects usually take 20% longer than planned to complete and are up to 80% over budget [1,2].

The chronic problems are dedicated to the unique nature of construction operations includng labor-intensive, complex, and fragmented. To take care of the problems, many developed countries have enhanced innovative construction technologies in combination with a variety of digital technologies. This phenomenon has been referred to Smart Construction [3,4] or Construction 4.0 [5–7].

Among the technologies, Unmanned Aerial vehicle (UAV), known as a drone, has been recently well acknowledged as a significant technique for collecting valuable data in diverse construction processes. DroneDeploy, a cloud software platform for commercial drones, presented remarkable statistics on drone application in 2018 [8]. It pointed that drone use in the construction industry has raised steeply up to 239% compared to 2017, which is much greater than other industries. According to Allied Market Research, the global market size of construction drones was valued at $4,800 million in 2019 and is estimated to move up to $11,970 million by 2027 [9].

A drone does a similar task to laser scanning (LS) in monitoring as-built construction quality through Scan-to-BIM process [10,11]. Both technologies transfer the as-built conditions of an object into the computer world as a 3D BIM model and make the BIM model be compared with the as-planned data of the object. As well, by means of the Scan-to-BIM context, the absent design data, e.g., 2D drawings, can be produced through Reverse Engineering (RE). The RE processes allow engineers to come up with how a piece of a building has been created so that they can rebuild the product [12].

While the LS has been told the major technique of the Scan-to-BIM process, many digital professionals address the shortcomings of the LS such as time-consuming process, static nature in collecting data, and casting a shadow due to scanning mechanism [13] and emphasize that drones are an alternative which readily recovers the problems of the LS. A drone is well employed when capturing the facades of facilities due to its speed. Different from laser scanners, the drone can scan rooftops. Owing to its mobile character, the drone undergoes much less shadowing from adjacent objects. The drone technology delivers the precise point clouds that are to be processed to BIM software such as Revit and Archicad to generate a 3D model. It is the reason why UAV-to-BIM is referred to interchangeably with the Scan-to-BIM [14].

In 2018, the Ministry of Land, Infrastructure and Transport, Korea (MOLIT), the main governmental organization in charge of managing public policies to provide quality infrastructures in Korea, established "Smart Construction Technology Roadmap" as the policy of implementing Construction 4.0 and announced the plan to adopt the drone for enhancing the as-built quality of major public projects by 2025 [4]. It is necessary for Korean contractors to train their engineers to be competitive in operating the drone. However, the drone is *not so* popular in the construction projects in Korea. Among 12,651 general contractors nationwide, only top 50 level contractors have from time to time utilized the technology in their projects [15].

A successful drone flight is not just operating the equipment, but gathering the image data and editing the data to well fit to the objective of the intended operation. The tasks require skills and experience. T*he universities where Construction Engineering and Management (CE&M) program have been implemented in Korea are requested to develop the curriculum for providing drone education for the engineers. While a number of the schools deliver either graduate or undergraduate BIM curriculum, they have scarcely operated the drone or the LS curriculum.* The CONECTtech Lab in GeorgiaTech, Georgia, USA has recently carried out a course called "Technology Applications in the Construction Industry [16]." The course encompasses multiple construction technologies, i.e., the LS, 4D BIM, photogrammetry, virtual reality, mobile applications and project management software. But the major concentration and attraction for students of the course is positioned on drones. The CONECTtech Lab provides a good reference for Korean universities to develop a drone oriented curriculum in the CE&M program.

*There are very few drone experts in Korea knowledgeable enough to develop the curriculum. Developing the curriculum should systematically organize c*lear learning objectives, proper methodologies to the objectives, potential limitations, the amount of time required, and the final product of education [17,18]. *Each component affects and interacts with others. To avoid trials and errors in progressing the curriculum and successfully implementing it later on, it is very essential for the schools to implement a preliminary* study based on experimental drone application so as to specifically identify the necessary education for drone beginners and the potential risks that lie hid there. On the basis of the findings from the study, a comprehensive drone curriculum for the engineers can be initialized in the end.

The main objective of this study is to perform the preliminary study through experimental drone application with drone beginners in the Korean construction industry. The study empirically identifies the pros and cons of the drone in monitoring as-built conditions of a facility and the needs for collaboration of the drone with the LS technology. Based on the study result, the recommendations are identified that would be beneficial to promote the comprehensive drone curriculum to support the engineers to enhance the as-built quality of facilities compared to their as-designed data. In the process of identifying the recommendations, the following questions are specifically answered: (1) is it necessary for developing the drone education curriculum in the universities for construction engineers?; (2) what contents are essentially embraced in the

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curriculum?; and (3) what formats and supports are desirable to successfully develop and implement the curriculum?

1.2. Research Methodology

The research objective was met through following the five activities: (1) reviewing the existing body of knowledge on a drone and a laser scanner in construction; (2) preparing for the experimental operation of the technologies, i.e., participants, equipment to be used, facilities to be studied, and professionals who can support the experiment; (3) implementing the operation of the equipment around the facilities; (4) presenting the findings from the experiment and discussing needs for education; and (5) identifying the recommendations valuable for the schools to exploit a comprehensive drone curriculum. Figure 1 shows the sequential procedures of the study.

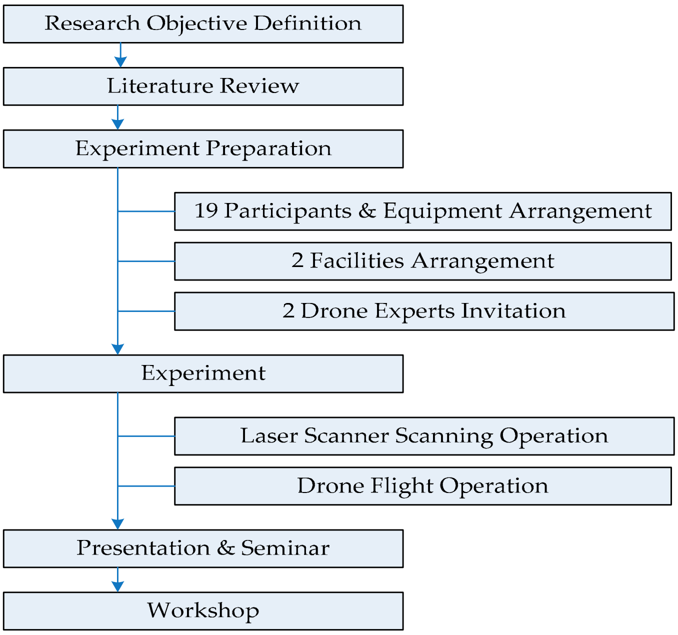

Figure 1. Research Procedures of the Study.

In the step (2), the authors arranged 19 students in the Free-form Facade Engineering (FFE) class as the participants of the experiment, which is one of the existing CE&M classes at Seoul National University of Science and Technology (SNUST) in Seoul, Korea. The class has used the LS technology for several years to educate how to measure the construction quality of the free-form building facades. The authors incorporated a drone education module into the class to test the usability of the drone and to compare the distinctions of the two technologies in capturing as-built conditions of a facility. Twelve out of the 19 were undergraduates and the other 7 part-time graduates. Table 1 summarizes the statistics regarding the 19 participants of the experiment.

Two drone training professionals were invited to guide the experimental activities of the participants from a private drone flight training institution. The role of the professionals featured supporting the authors to manage experimental procedures overall and participating in the workshop after the experiment. As well, 2 facilities with different shapes and complexities in the SNUST campus were arranged as the subject facilities to be experimented.

Table 1. Demographic Information of the Experiment Participants.

Gender		Age		Construction Job Experience		Drone Familiarity	
Male	13 (68%)	21-30	12 (63%)	5 yrs or Less	12 (63%)	Yes	0 (0%)
Female	4 (32%)	31-40	4 (21%)	6-10 yrs	4 (21%)	No	19 (100%)
		41-50	3 (15%)	11-20 yrs	3 (15%)		

In the steps (4), after finishing step (3), a presentation seminar was implemented. The participants presented their experimental findings, problems, feelings, and any difficulties freely in the seminar. The authors and the two professionals participated in the seminar to discuss and critique the findings and deliver their experience regarding those items.

In the step (5), the workshop having a Focus-group Interviews (FGI) format was conducted with the two professionals and the 7 part-time graduates to specifically figure out the recommendations beneficial for developing the drone curriculum on the basis of the results in step (4). FGI are interviews operated with a group of participants to build up with diverse information [19]. The authors performed the workshop instead of a questionnaire survey since the former can get more specific and comprehensive findings.

2. Literature Review

2.1. Industry 4.0 and Construction 4.0

Industry 4.0 have led distinguished technological advancements worldwide for the last 10 years. The German Federal Government (GFG) defines in 2011 Industry 4.0 as "a new technological age for manufacturing that uses cyber-physical systems and IoT to connect production technologies with smart production processes [5]." Schwab [20] later described it as the phase that enables the rich combination of people with machines by means of the aid of information technology. As well, Helman et al. [21] explained it as a new model of value chain throughout the lifecycle of merchandises.

Construction 4.0 is the term used to represent Industry 4.0 in the construction industry [22]. The first article that mentioned Industry 4.0 along with construction was shown in September 2014 [23]. Regarding Construction 4.0, Ronald Berger initially described in his article in 2016 [24]. The European Industry Construction Federation (FIEC) described it as the representation of the Industry 4.0 in the construction industry to effectively generate and manage a variety of built facilities through digitalization [25].

2.2. Drone & LS Application in Construction

The LS digitally takes the as-built configurations of physical objects into the computer world by a line of laser light [26]. The drone performs similar function to a laser scanner. Both of them have become an important method necessary for meeting the Scan to BIM cycle [10,11]. Relying on the large amounts of data from the two technologies, architects and project managers can approach to strong understandings that allow for having a very practcal model of the project. This is crucial to getting informed and data-driven decisions and significant for obtaining as-is circumstances and crafting subsequent design changes. In the Scan to BIM procedure, the image occupied by the two technologies is conveyed to 3D context by using softwares which shift the scanned image to the BIM world for the purpose of producing precise as-built models [27].

By means of the Scan to BIM context, the overlooked design data, e.g., 2D drawings or 3D models are made through Reverse Engineering (RE). The RE is, frequently referred to back engineering or reverse design, the procedure where diverse products are disintegrated to mine design intelligence, codes, and information from them [6]. Engineering generally creates drawings of the product to be manufactured based on engineering translation and the product is manufactured on the drawings. But, in the domain of the RE, the product drawings are mined out from the finished product. The RE process allows for coming up with how parts of a product are originated so that makes it possible to rebuild it under the circumstance where the drawings are not available.

Ock [11] presents the RE process through a case study as shown in Figure 2. The image in Figure 2-(a) shows the scanned facility having 2,900m^3 with two-story and 418 m^2 gross floor area. The opening step of the LS was to establish scan points. The image in Figure 2-(c) demonstrates 6 scan points to achieve the point clouds of the facility, 5 positions round the facility and one on the rooftop. The positions were prescribed to fortify sufficient overlay of scanned areas to secure a concrete configuration of the facility. Light green lines about the 5 red circles in the picture in Figure 2-(c)

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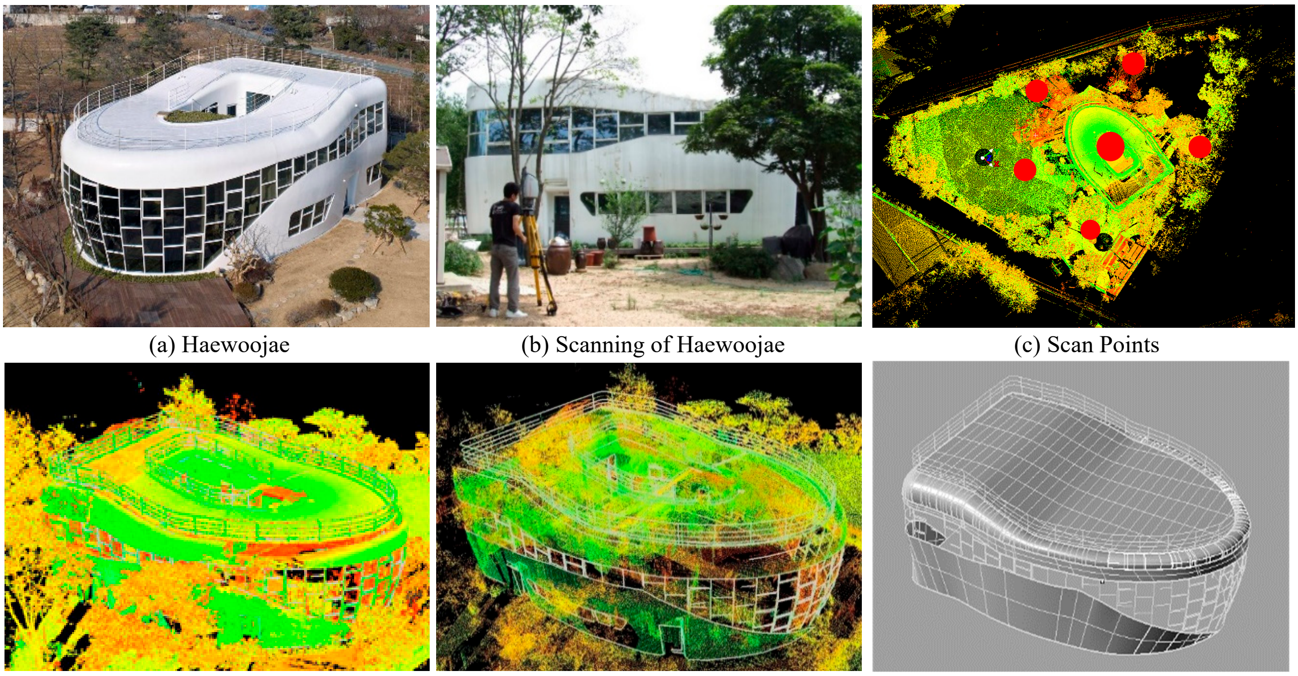
shows the borderline of the facility. The scanned results were then sophisticated through eliminating needless noise for reshaping the facility and merged together. Merge process was implemented along with the overlapped positions. On the basis of the merged shape, the outline and surface of the facility were generated as presented in Figure 2-(d), (e), and (f).



(a) Haewoojae (b) Scanning of Haewoojae (c) Scan Points

(d) Merged Scan Data (e) Outlines of Scan Data (f) Final Surface Model

Figure 2. An Example of Reverse Engineering based on the Scan-to-BIM Process [14].

2.3. Drone Education

A drone has been extensively operated to collect data throughout diverse careers and research fields. This phenomenon has integrated drones into education in the engineering, construction, science, and technology professions. Al-Tahir et al. [28] suggested three methods to utilize drones for education: carry out a capstone design using a drone, combine a drone operation into a current training program, or develop a new program totally on a drone.

Bolick et al. [29] developed the drone education program which included lectures and lab exercise for the students of the natural resource science. The students were trained the procedures of acquiring and processing drone data through lectures and videos of drone simulation. Whilst the students expressed positive opinions overall about the drone education program, some of them stated their preference to hands-on experience rather than simulation. As well, He et al. [30] devised a virtual drone training module to educate students how to obtain and process drone data into a 3D model reconstruction of an open-pit mine.

Although it is presumed that virtual drone education is beneficial for comprehending drone usage in construction, the best practice is definitely to perform in-person education. Sanson [31] introduced that the Civil and Construction Engineering Technology (CCET) Department of Youngstown State University (YSU), Ohio, USA has taken actions to employ drones in their curriculum. As well, as mentioned earlier, the CONECTtech Lab in GeorgiaTech, Georgia, USA has recently carried out a new course called "Technology Applications in the Construction Industry [16]." The course encompasses multiple construction technologies, i.e., LS, 4D BIM, photogrammetry, Virtual Reality (VR), mobile applications and project management software. But a main concentration and the major attraction for students of the course is positioned on drones.

The construction industry in Korea faces difficulties in utilizing drones as well as laser scanners. The major challenging hurdle is to find a skilled and knowledgeable manpower. While a number of

Korean construction companies still hesitate to adopt digital technologies to their business being with the innate conservatism of the construction industry and anxiety in mind owing to their unfamiliarity with the technologies, a number of construction professionals acknowledge the digital technologies as an essential tool for business sustainability in the future. To stay competitive in the digitalized market trend, construction professionals should keep on upgrading themselves to be knowledgeable about applying the digital technologies to their business.

2.4. Drone and Sustainability

The construction industry worldwide has been considered as a main donor to global carbon emissions, accounting for about 11% of global CO_2 gas emissions [32]. More than that, the built environment including buildings and social overhead capital promote to 40% of yearly energy consumption and 30% of all energy-related CO_2 gas emissions [33]. As such, the construction industry should perform a significant role in the transition to a zero-carbon world. Sustainable construction is the philosophy and the methodology in performing the role focusing on sustainability [34]. There are two directions that lead to sustainable construction: using recyclable and renewable materials and utilizing methods that can minimize energy spending and waste production.

A drone is one of the methods that help the construction industry become more sustainable. It can keep contractors on regularly monitoring and inspecting construction progress and recognizing problems in real-time to input adjustments as necesssary. This can support to lesson rework and decrease the carbon footprint of construction projects. When work is done improperly in the projects, contractors should extend project schedules and frequently assign more cash and resources to rework. Actually, greater than 30% of total construction work on average in a project is connected to rework, squandering resources and increasing costs [35].

For the purpose of decreasing the ecological effect from fuel burn, contractors are able to utilize drone data to efficiently assign heavy equipment on the construction site. Since drones can precisely measure different areas for a project during the planning process, the contractors can prevent earthmoving equipment from unnecessarily moving back and forth across the jobsite or from waiting idle with engines being operated [36]. As well, the drone can augment jobsite safety by finding risks and hazards even before the first day on the job. By combining this activity with the pre-planning process, the contractors can prepare to work around the risks.

Balasubramanian et al. [37] proposed an inclusive Construction 4.0 sustainability context that ascertains the Construction 4.0 technologies including a drone and their optimistic and pessimistic effects on social, environmental, and economic sustainability. The findings specified that the sustainability framework could be applied to the enhancement of the suitable positioning of digital technologies for sustainability.

3. Experimental Design

3.1. Course Description

As mentioned earlier in the research methodology section, a drone was applied to the FFE class. The class has been open several years before to provide students with procedures and theories of designing free-form façades based on the principles originated by Frank Gehry, the distinguished free-form building designer in the USA [38]. The class has utilized the LS technology to secure as-built quality of the free-form facades, conducted the data superimposition technique to measure discrepancy between as-built and as-designed free-form facades, and implemented the RE procedures in conjunction with LS application. The FFE is a three-credit undergraduate elective coursework and can be taken at the graduate level. The students in the course are in general architectural-engineering major and the majority of enrollment are seniors with a few juniors and graduate students, typically having more or less 20 students.

3.2. Experimental Settings

Nineteen students, i.e., 12 seniors and 7 part–time Master level graduates participated in the experiment. Table 2 represents the Construction Capacity Evaluation Criteria (CCEC) prepared by the MOLIT, Korea in 2021. The CCEC, developed since 1996, groups Korean general contractors into 8 levels in accordance with their contract volume last year, technical competitiveness, and financial status [39]. Belonging to a higher level indicates that the contractors in the level can be awarded more volumes of works than the contractors in lower levels. The CCEC, however, does not describe how competent contractors are in effectively utilizing digital technologies. Among the 7 graduates, 4 have been working for the companies in the level 1, and 3 others in the level 2. All of the 7 graduates have had more than 6-year field experience as a quantity surveyor, scheduler, or field manager. As a matter of course, the number 7 is too small to represent reality of the digital innovation levels of Korean construction engineers. However, it could be a clue to infer that many Korean companies even in Level 1 and 2 are simply in infancy toward pursuing digital implementation using drones or laser scanners.

Table 2. Construction Capacity Evaluation Criteria in Korea [39].

Level	Construction Contract Volume Last Year (M: million)	Numbers	The Predesignated Scope of Project Sizes to be able to Contract (Before Bidding Price)	
			Civil Works	Architectural Works
1	More than $500 M	58 (0.46%)	More than $142 M	More than $100 M
2	$500 M - $100 M	137 (1.08%)	$142 M- $79 M	$100 M - $79 M
3	$100 M - $50 M	176 (1.4%)	$79 M - $46 M	
4	$50 M - $27.5 M	302 (2.4%)	$46 M - $33 M	
5	$27.5 M - $16.7 M	500 (4%)	$33 M - $18 M	
6	$16.7 M - $10 M	823 (6.5%)	$18 M - $11 M	
7	$10 M - $6.7 M	640 (5.05%)	$11 M - $6.7 M	
Others	Less than $6.7 M	10,015 (79.2%)	Less than $6.7 M	
Total		12,651 (100%)		

Two facilities were arranged for the experiment as shown in Table 3. Each of the facilities includes the different shape and complexity. Since the experiment was proceeded in the campus, the authors had to be very careful in selecting the facilities in order not to cause any incidents to other buildings as well as pedestrians and any troubles to other classes due to drone noise. The size and shape of the facilities were chosen to support the students to comprehend the workability level of a drone as well as a laser scanner in capturing as-built environments of the facilities in reflection of their configuration.

The first facility in Table 3 is a one-story and small power plant. It is located at the outskirt of the campus so that little interference and congestion by pedestrians was expected during the experiment. The exterior of the facility is finished with white painting and the configuration of the parapet and the chimney impose a little complexity on the facility. The second is a playground stand, located at the edge of the campus as well so that little restrictions seemed to be projected to students' activities in the experiment. The exterior of the stand is constructed with steel pipes and panels. The canopy roof and the stand chairs seem to make it complex to gather the as-built data of the facility.

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Table 3. The Facilities Used in the Experiment**.**

	Facility 1	Facility 2
View		
Details	A Power Plant, One-story, 360m², Rectangular Shape, No Canopy, Several Projecting Structural Elements	A Playground Stand, 1,060m², Rectangular Shape, Canopy Roof

The authors organized the students into 6 groups, i.e., 3-4 students in a group. While it was desirable for each student to be involved in the experiment of the two facilities, therefore possible to get more experiment data, due to time limitation of a semester, three groups of students were solicited to perform the experiment of drone flight toward one building, e.g., groups 1, 2, and 3 to the power plant.

The experimental FFE class consisted of two modules: lecture module and experiment module. The lecture module progressed until the midterm covering the theories of designing free-form façades, securing as-built data of the facades with the drone and laser scanner, and measuring discrepancy between the as-built and as-designed. After the mid-term, the students got involved in the experiment module for 7 weeks. The experiment covered six steps: (1) a theory and equipment-learning session; (2) a laser scanning operation; (3) a laser-scanned data development; (4) a drone flight operation; (5) a drone-flown data exploitation; and (6) an experiment results presentation. Based on the experiment results, the students were requested to figure out the pros and cons of the two technologies, the good or bad outcomes from the technologies in the experiment, and analyze the usability of the technologies in conjunction with the distinct features of the facilities.

3.3. Equipment

Table 4 shows the equipments as well as the related software used in the experiment. Among a number of laser scanners, the study utilized Faro Focus 3D-X330 Time of Flight (TOF) scanner. A TOF laser scanner calculates the coordinates of its surrounding context in conjunction with the amount of time a laser signal needs to get back to the scanner after reflected [40]. This procedure occurs a number of times until the designated range of data is achieved.

Two quadcopter drones were used in the experiment including DJI Mavic 2 Pro and DJI Phantom 4 professional. The former features a 3 axis gimbal with a 1* CMOS camera that provides 4K video, 20-megapixcel photos and filters [41]. It has a maximum flight speed of 72km/hr and a maximum flight time of 31 minutes. The latter contains 12.4 megapixcel camera with 4K resolution video at up to 30 frames per second recording capabilities [42]. Its maximum flight time is up to around 28 minutes. The main drone prepared for the experiment was DJI Phantom 4 professional. DJI Mavic 2 Pro was adopted right after the Phantom 4 became unworkable due to the flight accident happened in the middle of the experiment.

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Table 4. The Equipment Used in the Experment.

	Drone		Laser Scanner
Equipment	DJI Mavic2 Pro	DJI Phantom 4 Professional	Faro Focus 3D-X330
			
	Weight 0.9 kg Battery 30 Minutes	Weight 1.3 kg Battery 25 Minutes	Weight 5.2kg, Battery 4.5hrs Measuring Range 0.6 – 330m
Software	Pix4D Mapper		Revit Recap
	A photogrammetry software to transform the image from a drone to point cloud		

4. Experimental Process and Results

4.1. Flight Licenses and Permits

As the initiation of the experiment, the students were solicited to take a 6-hour e-learning class regarding drones delivered by the Korean Transportation Safety Authority (KOTSA), a public entity to shelter lives and properties in all fields such as railroad, land, and aviation in Korea [43]. The contents of the e-learning class cover the fundamental knowledge of airspace system, particular operation limits, UAV platform requirements, and human operator' obligation.

The e-learning class is a mandatory qualification to fly drones with weight of 0.25–2kg. To hover drones bigger than the size, operators should take a strict license exam and register the license. According to Korean Aviation Safety Act (KASA), the license requirement is different with respect to the weight of drones ranging from the 1st to 4th levels: the 1st class license covering drones with 25-150 kg, the 2nd class 7-25 kg; the 3rd class 2-7kg, and the 4th class 0.25-2kg. While the first 3 level licenses require a certain period of aviation experience and an exam, the 4th level demands only taking a 6-hour e-learning class without any aviation experience as well as an exam.

The experiment was not subject to any aviation approval from public authorities. As a matter of course, in Korea, when a person intends to operate the flight using a drone, he/she should obtain an approval for flight from the MOLIT by Article 127, KASA. However, the Article provides clear exceptions of the approval under the following circumstances: when the flying altitude is less than 150m or when the weight on board including drone self-load is less than 25kg. The drones adopted in the experiment were only 0.9-1.3kg and the flight height was less than 50m.

4.2. Learning Session Proceeding

All the 19 students attended the learning session to clarify the operational process of the LS and drone flight and the activities to be executed in the experiment. In the first place, the scanner, Faro Focus 3D-X330 was introduced to the students. Keeping the scanner on, the authors demonstrated not only how to set up the scanning parameters in the scanner to adjust scan resolution and quality, scan range, color setting, and scan duration but also how to reconstruct the as-built environment through refining and merging point clouds captured by the scanner.

As stated earlier, in order to secure safety during the experiment, two drone training professionals were invited from the private drone flight training institution which has been certified as a drone education provider in accordance with Article 126 (Designation, etc. of Training Center

Specializing in Ultra-Light Vehicle), Korean Aviation Safety Act (KASA) [43]. The professionals delivered the presentation regarding the components of the two drones and their functions. They also demonstrated drone flights a few times by performing the following tasks: taking off and climbing to an altitude of 50m, hovering in place, performing diverse flight patterns manually, showing automatic flying patterns, taking images of the facilities, and returning to the home location and landing.

4.3. Experiment Proceeding – Laser Scanning

4.3.1. Setting up Scan Points

The first step of the LS was to establish scan points. Table 5-(a) and (c) present 7 and 9 points founded to achieve the point clouds of the facilities 1 and 2 respectively, maintaining enough intersection of scanned areas thus gaining assertive shapes of the facilities. Each facility was scanned in the field just once by all the student together as a team. The individual group of the students was then requested to refine point clouds by removing unnecessary noise in each scanned area and merge together to form a 3D model along with the overlapped location.

For the facility 1, the LS was conducted for a total of 3.5 hours at 7 locations, maintaining a distance of 25m from the center of the facility. In case of the facility 2, the laser scanner placed 4 locations at a 30m distance from the center of the facility, 2 locations at a 10m distance from the side walls of the facility to scan the lower part of the canopy and stand seats, and 3 locations at a 5m distance from the backside wall of the facility to secure data in a narrow space between the stand and adjacent structures. A total of 6 hours was spent in the LS of the facility.

4.3.2. LS Application Results

It is well known that the LS allows contractors to provide both accurate and current data beneficial throughout the different design and construction stages, verify as-built models, and monitor progress on a project. Opposite to the usability, it also has certain weakness. The major disadvantage of laser scanners is the immobile nature of their collecting data [13]. Laser scanners assemble point clouds by spinning laser beams from a designated position and gauging the time taken for the laser to return to the scanner. As the laser tours only in a linear line, if any barrier is between the scanner and the object, a shadow is thrown that definitely triggers holes in the data.

To get over the shortcoming, the scanner should be adjusted around on site to make sure the particulars of the object are captured. Selecting suitable scanner positions is very labor-intensive and requires experience and skill. Even with the most skilled users, there are still surfaces, such as roofs, which cannot be scanned.

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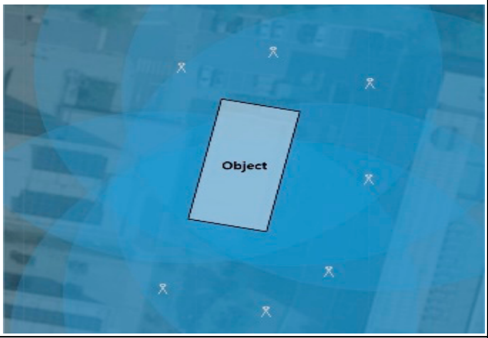
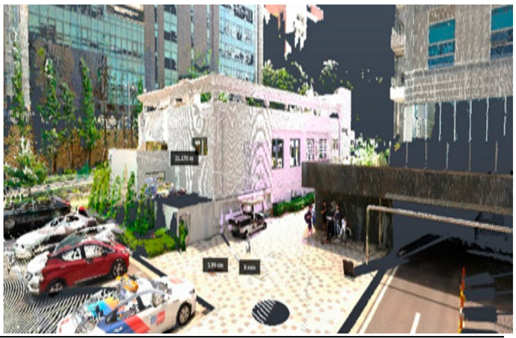
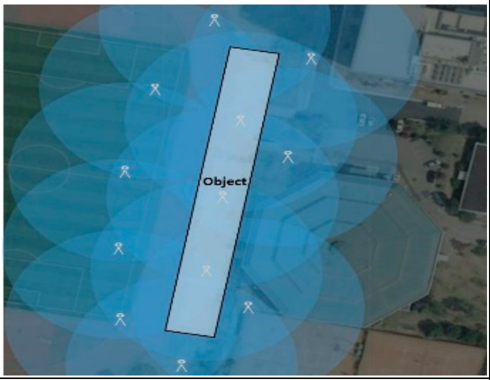
Table 5. The *Results of the LS Application to Facilities 1 and 2.*

Facility 1		
	(a) Laser Scanning Posts	(b) Scanned Results
Facility 2		
	(c) Laser Scanning Posts	(d) Scanned Results

In the expriment, the students were requested to identify the disadvantegeous circumstances that influenced the quality of the scanned images in addition to the drawbacks described above. They were also solicited to estimate if a drone could be an alternative to be able to overcome the disadvantageous situations. The followings summarize the findings from the LS application by the students and the critiques identified through the presention after the experiment:

1. Picture (b) in Table 5 shows the 3D modeling result of the facility 1 based on the point clouds generated in the experiment. The students indicated that since the main scanning locations were placed close to the parking lots of adjacent buildings as shown in Figure 4-(a), the frequent vehicle traffics and reflection lights from the vehicles were likely to hinder them from having high quality outputs from scanning.
2. The exterior of the facility 1 is finished with white painting that reflects light. The bending in the point clouds of the picture (b) in Table 5 seemed to be occurred due to the light reflection. Previous research presents that strong light and the glare of the sun can limit the scanner's ability to capture desired objects [44].
3. The authors guided the student that whenever scanning a facility, the primary task was to organize the scanning job overall, which covered imagining the desired scan result, observing the areas to be scanned, and then simulating to figure out the best scan positions to achieve the result. Figure 3 shows the scanned outcomes of the facility 2. These were the outcomes from the test scanning of the facility to select appropriate scan positions for the experiment. It is quite easy to acknowledge that the scan points were too far from the object so that the scanned results were not able to deliver what constructional elements were involved in the facility.
4. As stated above, 3.5 hours were taken to scan the facility 1 and 6 hours to scan the facility 2. In case of scanning buildings, properly estimating the amount of time of scan operation in the field and the frequency of pedestrian traffics around the buildings allows for choosing the best time to perform scanning [44]. People and vehicles moving around the buildings can act as temporary obstacles that cause shadows and damage the quality of the scanning, frequently leading to rescanning. The two pictures down side in Figure 3 demonstrated the shadows triggered by the people between the object and the scanner. The shadows lead to missing data and noise in point clouds, requiring a big investment in time and manual effort to remove.

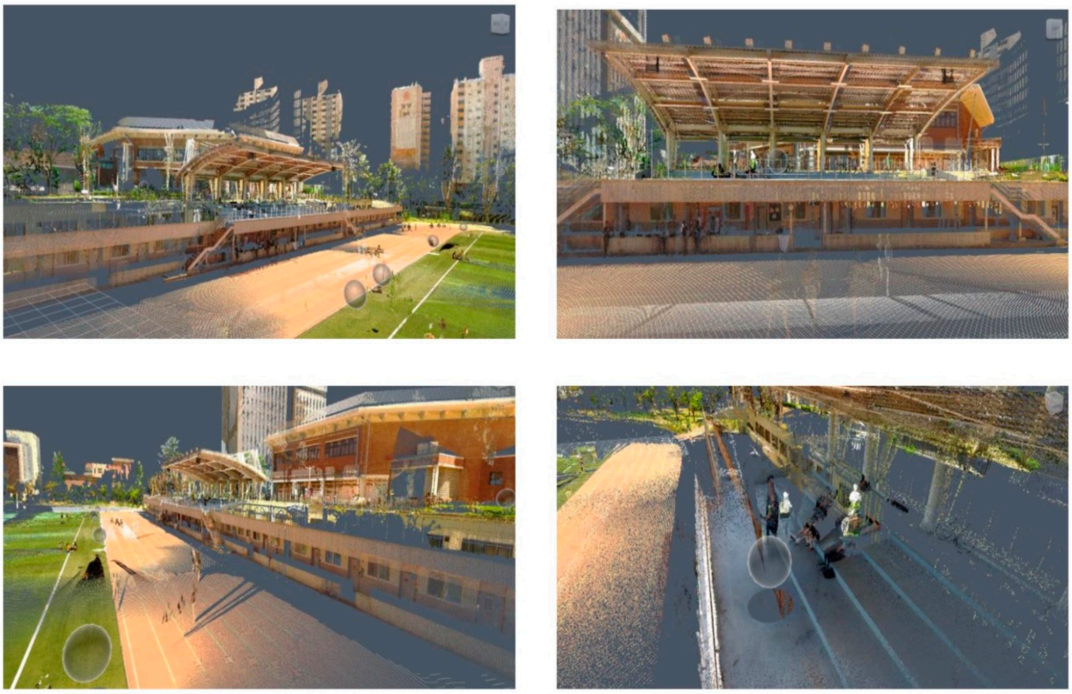


Figure 3. The Results from the Test Scanning of the Facility 2.

5. The students got to appreciate the difference of scan resolution, i.e., high or low resolution, through comparing the scan result represented in the picture (d) in Table 5 with those in Figure 3. Resolution is the smallest possible distance between any two given points within 3D model [45]. The higher scan resolution, the better details of the scanned data as well as the more scan time. The students were instructed how to set scan resolution parameter in the learning session of the experiment for efficient scanning operation.
6. Since the scanner set on the ground, the scanning operation was proceeded from the bottom to the top of an object using a bottom-up angle. Because of the bottom-up angle layout, certain parts of a building's exterior were not accessible to capture the scan data, such as a rooftop. Pictures in Figure 3 and the picture (d) in Table 5 did not deliver the overall roof shape of the facility 2 due to the reason. The scanner should have been positioned in the rooftop of the stand to obtain the point clouds of the stand roof shape. There was no ladder or corridor that allowed for carrying up the laser scanner to the position. This constraint made it impossible to complete reconstructing the overall 3D shape of the stand.

4.4. Experiment Proceeding – Drone Flight

There are three types of drone operation control in accordance with the intervention level of a drone pilot: a manual control, an automatic control, and an autonomous control [46]. Whilst the **autonomous** control refers to conducting a drone flight without the interference of a pilot with the help of AI, the **automatic control indicates** that a drone flies pre-set routes designated by a drone pilot before starting the flight. A manual control indicates that the pilot determines the drone's flight path. The authors guided the students to utilize the manual control for the purpose of leading them to be intimate to drone operation.

4.4.1. Drone Flight Routes and an Accident

The blue dotted lines in the pictures of Figure 4-(a) and (b) show the planned routes on which the drones were supposed to be aviated along the facilities. Each group of the students flew the drones around one of the facilities assigned to them for around 25-30 minutes while taking photos. In case of facility 1, operation was conducted to secure the overall data of the facility by maintaining a distance of 8m to 25m from the center of the facility. An average of 83 images were collected with

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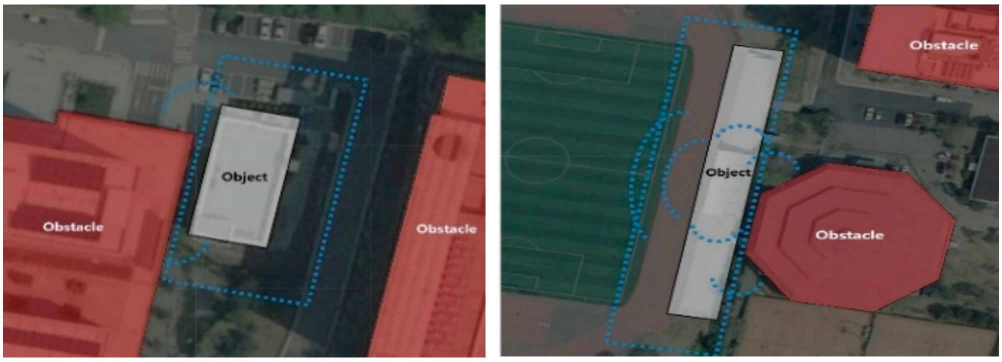
an overlap of 50 to 60%. In the part where filming was disadvantageous due to adjacent facilities, 10 pictures of each end were additionally filmed with an overlap of 70%. The angle formed by the camera was maintained at 30 to 60° . In case of facility 2, by maintaining a distance of 20m and 60m from the center of the facility, manual shooting collected an average of 224 images in 30 minutes with an overlap of 40 to 50%. The angle formed by the camera was maintained between 30 and 90° .



(a) Facility 1 (b) Facility 2

Figure 4. The Drone Aviation Routes of Facilities 1 & 2.

In the middle of the experiment with the DJI Phantom 4 professional, a drone crush accident happened around facility 1. As shown in Figure 3-(a) and Table 5-(a), facility 1 was located very close to an adjacent building. The distance between facility 1 and the adjacent building is 5m. According to the student of the accident, when he/she moved the drone promptly back from the direction of the adjacent building to facility 1, the drone was crushed to the side wall of the building and fell down to the ground. Fortunately, there was no pedestrian in that morning. Three propellers were broken down but the students participating in the experiment stood from the accident spot away more than 10m, so the fragments of the propellers did not hurt anyone.

A number of previous drone crush reports identify a variety of reasons for drone accidents such as malfunctioning rotors, no Global Positioning System (GPS) signal, compass error, disconnected video transmission, incorrect home point, power failure, insufficient battery, and pilot inexperience [47,48]. It was not clear why the accident occurred in the experiment. But considering such comments by the students in the experiment as that the drone did not show any problems before the accident, the cause of the accident seemed to be abrupt operation of the control sticks in the remote controller due to insufficient flight practice. The participants empirically realized that although the drone equips an obstacle sensing system that can identify obstacles in front and bottom of it and support to avoid clashes, the system was not a panacea to prevent an accident.

4.4.2. Drone Application Results

Table 6 shows the transformed meshed shapes of facility 1 and 2 respectively from the point clouds with the photogrammetry software, Pix4D mapper, based on the number of pictures taken by each group of students with the drones. The Pix4D mapper is a drone mapping software to work with drones to transform a large number of images into accurate point clouds and 3D textured mesh [49]. The softwares that provide similar function to Pix4D mapper include PhotoScan, DroneDeploy, and Precision Hawk.

Reviewing 3D modeling results in Table 6, i.e., pictures (b), (c), (d) of facility 1 and pictures (f), (g), and (h) of facility 2, the shapes modeled with Pix4D mapper were much vague to figure out the configuration of the facilities compared to the images taken by the drones, i.e., picture (a) and (e). The overall quality of the experimet results were worse than expected and acknowledged not to be applicable to the procedure of develop a UAV-to-BIM application without certain remedy actions to improve the quality. Whilst it is necessary to analyze and research the reasons for those elusively transformed outputs, it seems to be obvious that the time given to the students was not enough to

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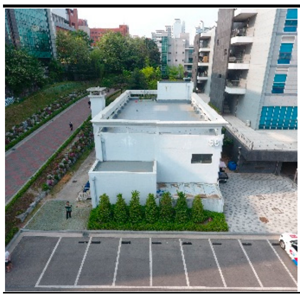
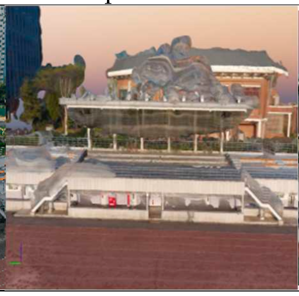
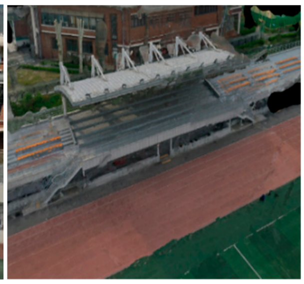
reconstruct the images to a 3D model from drone beginners' point of view. A number of drone professionals emphasize that *operating a drone is more about the data and presentation than about the flying. The study confirmed the expression and the need* for advanced education to comprehensively plan a drone flight and skillfully handle the outputs from the flight.

Table 6. *The Results of the Drone Application to Facilities 1 and 2.*

			
(a) Image from Drone	(b) Transformed Meshed Shape with 56 pictures	(c) Transformed Meshed Shape with 87 pictures	(d) Transformed Meshed Shape with 53 pictures
			
(e) Image from Drone	(f) Transformed Meshed Shape with 168 pictures	(g) Transformed Meshed Shape with 352 pictures	(h) Transformed Meshed Shape with 83 pictures

Whereas 30 minutes were taken for each group of the students to photograph the individual faciliy, manipulating the photo images with the Pix4D mapper took 3 hours on average. After photographing the facilities, the students followed the modeling procedures presented in the Pix4D mapper manual to creat 3D models of the facilities consisting of initial processing, densifying point clouds, and delivering 3D textured meshes [49]. The followings summarize the findings from the drone experiment by the students and the critiques delivered through the presention after the experiment:

The students felt at first nervous about flying a drone but found that it was very much easier than expected as soon as the drone started to hover. They felt like moving it faster and faster just like a toy in spite of being educated in the learning session to fly it as slow as possible around the facilities to prevent any incidents from happening.

1. The drone education professionals pointed that safety should be a primary concern when dealing with a drone, however, during the experiment, safety around the experimental surroundings did not appear to be the first issue to be met. The learning session was too short for the students to understand that a drone was an aircraft system that should be managed methodically and strictly for safety as a unit including a pilot on the ground, the drone itself, a control system, and communication links.
2. Reviewing the accident case, it was very clear that if a building to be photographed with a drone was very adjacent to a nearby building, special caution was required to avoid disastrous incidents. As well, a specific image acquisition plan was necessary for accurate and sharp images reflecting the narrow configurations of the buildings.
3. In the pictures (f) and (g) in Table 6, it was easy to recognize noise above the roof of the stand. The students who worked on the facilities indicated that this could be caused by the rolling shutter phenomenon during the drone rotation process when photographing. It was discussed

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in the presentation session that the indication was not reasonable because before operating the drones, the shutter speed, aperture and ISO in the cameras of the drones were configured on automatic so that the shutter control hardly influenced the quality of the images taken.

4. Some students questioned that the noise in pictures (f) and (g) could be due to sunlight. They wondered if building façades were finished with the materials that reflected sunlight as described in the laser scanning experiment, errors in getting images were likely to occur. The 2 professionals explained whereas it might be one of the causes of the blurry modeling results, more realistic cause would be improperly acquiring the images. When obtaining the images, the first item to be satisfied with was to highly overlap between images since occupying the image dataset to create point clouds relies on visual similarities between the overlapped images.
5. Although overlapping the images was significant, it was questionable for the students to be able to maintain a suitable degree of overlap during the experiment since they were inexperienced in flying a drone and even worse, requested to use a manual flight mode in spite of the inexperience. Whereas more specific guides were available from the manual for securing enough overlap of the images such as "fly around the buiding a first time with a 45° camera angle; fly a second and third time increasing the flight height and decreasing the camera angle with each round; take one image every 5 to 10° depending on the size of the building and distance to it," the students should have practiced a lot to satisfactorily follow the designations in reality.
6. Pictures (b), (c), (d), (f), (g), and (h) in Table 6 are the representation of the 3D textured mesh delivered from the densified point clouds. Viewing pictures (c) and (h), in addition to the noise around the facilities, the roof and parapet shapes of the facility 1 and the corridor and roof shapes of the facility 2 were very undistinguishable and inaccurate. The mesh receives the point clouds as input. So, if the point clouds are noisy, the mesh also noisy. If the quality of the images is not high, the 3D Textured Mesh generated shows successively tendency of having holes or not being planar in planar surfaces due to the low quality of the point clouds.
7. Picture (d) in Table 6 was much clearer than any other pictures. The students in the group that worked on the picture (d) indicated they operated the processing options provided in the Pix4D mapper to edit and filter the noise in the point clouds and to improve the quality of 3D textured mesh, e.g., the noise filter processing option to furnish cleaner point clouds for datasets and the s**ky filter** processing option to **remove points** in the dense point clouds **associated with sky.**
8. On the contrary to the laser scanner, the drones could easily capture the rooftop images of the stand by means of a top-down angle. However, when taking images under the roof of the stand shown in pictures (f) and (g), a certain limitation was found caused by a gimbal configuration of the drones. The 3-axis gimbal furnishes a stable platform for the attached camera, tolerating for smoothly moving and capturing clear images. The gimbal installed in the drones could tilt the camera within a 120° range consisting of up to 30° upward and 90° downward from the horizontal line. However, due to the upward sloping limit of the gimbal, it was very difficult to capture the images in the ranges bigger than the limit. The difficulty leaded to shadowy images causing blurry shapes of the 3D textured mesh.

5. Recommendations

The authors conducted a FGI based workshop with the two drone education professionals and 7 graduates who participated in the experiment to identify the recommendations for developing the drone curriculum for the construction engineers. In the process of FGI, a moderator asks a question to the participants and allows natural conversation to rise with respect to the question. The authors played the role of the moderator and identified valuable recommendations with the interviewees together. The 9 participants were solicited to describe their opinion on the following questions: (1) is it necessary for developing the drone education curriculum in the universities for construction engineers? (2) what contents are essentially embraced in the curriculum? and (3) what formats and supports are desirable to successfully develop and implement the curriculum? The following are the recommendations acknowledged from the workshop:

5.1. The Need for the Curriculum

All the workshop participants agreed that the formal drone curriculum should be prepared the sooner the better for the construction engineers to keep up with the current digitalized market trend. While both a drone and a laser scanner allow for digitally restructuring accurate as-built models, the technologies include distinctive pros and cons respectively as shown in the experiment so that need to go hand in hand to successfully function construction quality monitoring. Compared to the LS, drone application is still in infancy level in all life-cycle stages of built environments in Korea. Educating how to collaborate a drone with a laser scanner will support the construction engineers to be confident and insightful in challenging construction operation.

As stated earlier, the majority of the engineers in the Korean construction industry are novice at utilizing a drone in the construction operation. While common drone training programs are available from the current market place, those are simply to deliver how to fly drones without covering the distinctive characteristics of construction operation. Construction activities are very systematic in the sequential processes of planning, design, construction, and maintenance. The BIM data generated in the former process should be used in the next process and applicable to meet very long-term sustainability of a construction output. The drone curriculum in conjunction with the CE&M context is expected to support the engineers to enhance productivity of their construction activities.

5.2. The Contents of the Curriculum

The participants came to understand that hovering *a drone was 20% of the drone job and the other 80% would be data processing.* As mentioned above, the drone training programs in the market is not to deliver the suitable capacity of managing the drone data such as point clouds, 3D textured mesh, and others, but simply to instruct how to fly a drone and get a license. The participants emphasized that the contents of the curriculum should focus on acquiring, processing, analyzing, and improving the drone data rather than on flying a drone. There are diverse commercial applications to handle the digital data captured with a drone such as Pix4D Mapper, PhotoScan, DroneDeploy, Precision Hawk, and 3D Robotics. The curriculum needs to figure out and deliver the common procedures and techniques involved in each of the applications.

The participants emphasized that the contents of the curriculum also needed to deal with drone risk. Flying a drone is very challenging, especially when people are first involved in drone operation. As shown in the experiment, accidents are too easy to happen. Drone risk embraces physical as well as non-physical, threatening safety, privacy, intellectual property, and operational security [50]. The curriculum must include how to establish safety protocols in the use of a drone. Rather than a manual flight, it was insisted to use best practices with the automation flight.

As shown in the experiment, even beginners in drone flight easily tend to regard drones as a toy and feel like flying them faster. Time, practice, and experience are required to be a skillful operator. Very few studies have explored the human aspects of drone flight, i.e., drone operators' reasoning capacity and job performance [51]. All the workshop members agreed that the curriculum should address human factors and human performance in drone flight in combination with safety, experience, and a risk management plan. Human factors indicates the variables that influence a human's capability such as external, i.e., light or noise, or internal, e.g., fatigue. Human performance, which is a function of human factors, denotes the human competence to positively achieve tasks [52].

The participants added that considering construction projects were operated anywhere in the nation, the curriculum should educate the construction engineers to understand the drone regulations such as prohibited areas of the drone flight and administrative procedures to obtain a flight permission in diverse regions. In Korea, according to the Radio Waves and Aviation Act, the drone flight is banned within a 5.5 km radius of airport, at an altitude of 150m or higher, near the cease-fire line, over the city of Seoul, in no-fly zones, and also over densely populated or over-crowed areas. As well, there is different administrative complexity for obtaining a drone flight approval depending on region by region. In construction sites, the needs for drone operation occur irregularly and frequently. The construction engineers, therefore, need to know the general procedures to obtain the approval while complying with the regulations in different jurisdictions.

5.3. The Desirable Formats of the Curriculum

There are generally two types of curriculum models: the product model and the process model [53]. The product model focuses on outcomes of the curriculum while the process model centers on how learning is developed over time. The workshop participants discussed that since the drone curriculum aimed at generating very clear digital outcomes by teaching the specific step-by-step procedures, the product model would be a proper setting to pursue. As well, among three curriculum design methodologies widely accepted in the field of curriculum development, i.e., subject-centered, problem-centered, and learner-centered, the subject-centered approach would be appropriate because the curriculum was supposed to be the basic one on which the problem-centered and learner-centered ones could be developed in the graduate study level.

The two drone professionals suggested that since flying a drone in the campus was very risky due to lots of students, traffics, and buildings, dividing the curriculum into two modules, i.e., a drone flight module and a data processing module, could be a reasonable approach to manage the risk. Through industry-academia collaboration, the drone flight module could be then outsourced to private institutions. Doing so, faculties could focus more on teaching the disciplines of processing drone data while mitigating the drone operation risk in the campus and the burden of hiring a qualified pilot for the curriculum.

Instead of dividing the curriculum, a different option was discussed, that is, to require students for a certain prerequisite to register the drone class. The prerequisite could be getting a drone license from private drone schools or taking on-line training courses. Some workshop participants were, however, skeptical to the option, pointing that it would not be workable because the option imposed extra load to the students. They insisted that before inventing the option, the suitable format of the curriculum to the entire CE&M program, i.e., a core course or elective course; the duration of the curriculum; the correlation of the curriculum with other courses in the program should be contemplated in the first place. Among the three different curriculum formats to introduce drones into education [28], the authors targeted to develop the curriculum as an elective course having the format of incorporating a drone education into an existing course in combination with the LS technology during one semester.

Developing the curriculum requires the school to provide diverse resources to purchase drones and insurance, outsource drone flight education, or hire full-time or part-time drone pilots. It was recommended that school administrative workforce should be consulted to secure the budget for the items, thereby making the curriculum realistically reasonable.

5.4. The Preliminary Curriculum Framework Recommended

Based on the experiment results and recommendations above, the workshop identified the preliminary curriculum framework shown in Table 7. As mentioned earlier, this research is a preliminary study to identify the necessary education for drone beginners to be knowledgeable about operating a drone and obtaining high quality modeling results.

Learning goals in Table 7 indicate the focuses to satisfy the expression of “knowledgeable about operating a drone and obtaining - - -” through education. On the contrary, learning **objectives** represent the specific and measurable sub-goals and inform particular learning outcomes. The learning objectives can then be broken down into small learning activities which stand for knowledge or skills that are necessary for meeting the relevant learning objective.

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Table 7. A Preliminary Drone Curriculum Framework.

Learning Goals	Learning Objectives (●) and Activities (-)
Understand a drone as a system that can capture existing surroundings with a camera	● Understand drone hardware, firmware, network system, and their functions - Recognize the different parts of a drone and their function - Study basic troubleshooting for common drone problems ● Understand basic drone movement and how to use a camera with a drone ● Understand safety precaution when using drones ● Learn how to aviate drones at manual, automatic, and autonomous modes - Practice hands-on hovering and landing and video simulation exercise
Understand the application of the LS to monitoring the as-built construction quality of a facility	● Learn the LS technique to capture as-built conditions of a facility - Practice the Scan-to-BIM process through a simple hands-on case study - Identify the influencing factors on the scanned results ● Understand the BIM data superimposition technique to measure the difference of the as-built from the as-planned - Practice the data superimposition through a simple hands-on case study ● Understand the pros and cons of the LS technique
Understand the application of a drone to monitoring the as-built construction quality of a facility	● Understand the effect on camera images from the interaction of diverse camera settings with natural conditions as well as image overlapping ratios - Analyze the image quality deviations depending on various interactions ● Understand how to make reasonable image acquisition plan ● Understand the data processing steps for obtaining high quality products - Study the functions installed in diverse commercial applications ● Understand the methods to improve the cons of the LS as well as a drone
Understand the restrictions, risks, and human performance involved in drone operation in construction projects	● Understand the legal requirements for flying drones in various project sites - Investigate flight permit rules in diverse regional jurisdictions ● Understand the effectiveness of a drone to enhance sustainable construction ● Recognize the significance of safety concern in drone aviation - Identify crush accident cases; investigate the reasons & results of the cases ● Comprehend the risks involved in drone operation - Develop a risk management plan for educational purpose ● Understand the significance of securing privacy from drone aviation ● Understand human factors and performance in drone flight

6.Discussion

The limitation of the study is that the recommendations were identified on the basis of the opinion and discussion of the 9 workshop participants. While it is expected that the findings from the study are reasonable and beneficial for the CE&M faculties to refer to when preparing a drone curriculum in universities, more comprehensive industry-wide opinions, possible barriers, and suggestions to get over the barriers are needed in future research to establish rationale for a further inclusive drone curriculum for the construction engineers. Apart from the research on the curriculum development, it is necessary in the future research to investigate the limitations that hinder spreading drone applications to construction projects and to definitize directions and specific methodologies to surmount them thereby keeping on upgrading the construction engineers.

7. Conclusion

The construction industry has been considered as a key industry that devotes to economic development of a nation. Construction professionals recognize that digitalization cannot be avoidable and digital technologies as an essential tool for survival. Among diverse digital technologies, a drone has been recently well acknowledged as a significant technique for collecting valuable data and insights in diverse construction processes. The MOLIT, Korea announced the plan to utilize the drones and the LS for monitoring construction operation quality in major public projects by 2025. Whereas contractors need to train their manpower, the two technologies *are not so* popular in construction projects in Korea and very few experts are available.

The Korean universities implementing the CE&M were requested to develop the curriculum for providing education of the technologies for the contractors. Developing a curriculum is the multi-step process of creating and improving a learning objective, teaching strategies, materials, and assessment. To avoid trial and error in progressing the drone and LS curriculum and successfully implementing it later on, it is very essential to perform a preliminary study to identify the needs for the curriculum. The objective of this study is to carry out the preliminary study through the experiment of drone and LS applications to the beginners in the construction industry and identify valuable lessons that would be beneficial to promote the curriculum.

The authors arranged 19 students, 12 seniors in undergraduate and 7 part-time graduates in the CE&M program at the SNUST in Korea as the participants of the experiment. Two facilities with different shapes and sizes in the campus were selected as the subject facilities to be experimented, i.e., a power plant with one story and $360m^2$ and a playground stand with $1,600m^2$. The authors incorporated a drone education module into one of the existing CE&M classes, called FFE in the SNUST. Two drone education professionals were invited from a private drone flight training institution to help the experiment.

In the experiment, Faro Focus 3D-X330 TOF scanner as well as two quadcopter drones including DJI Mavic 2 Pro and DJI Phantom 4 professional were utilized. The experiment consisted of six steps: (1) a theory and equipment-learning session; (2) a laser scanning operation; (3) a laser-scanned data development; (4) a drone flight operation; (5) a drone-flown data exploitation; and (6) an experiment results presentation. Based on the experiment results, the experiment participants figured out the pros and cons of the two technologies, the good or bad outcomes from the technologies in the experiment, and analyze the usability of the technologies in conjunction with the distinct features of the facilities.

After the experiment, the authors conducted a FGI based workshop with the two drone education professionals and 7 graduates who participated in the experiment. In the workshop, the 9 participants were solicited to describe their opinion on the needs for the curriculum, the contents of the curriculum, and the desirable formats of the curriculum as the recommendations from the study that are beneficial to develop the comprehensive drone education curriculum later on.

The recommendations include: drones and laser scanners need to go hand in hand to successfully function construction quality monitoring; the contents of the curriculum should focus on processing drone data rather than on flying a drone; also need to address *drone risk and* human factors as well as human performance in drone flight in combination with safety, experience, and a risk management plan; the product model and subject-centered curriculum design are suitable to the curriculum, separating a drone flight module from a data processing module in the curriculum and utilizing industry-academia collaboration can be a reasonable approach to manage the drone risk.

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References

1. McKinsey & Company. *Executive Summary: The Next Normal in Construction: How Disruption is Reshaping the World's Largest Ecosystem*, June 2020.
2. www.mckinsey.com/capabilities/operations/our-insights/imagining-constructions-digital-future (accessed on 1 December 2022)
3. Construction Leadership Council (CLC). Smart Construction, *A Guide for Housing Clients*, UK, 2018, www.constructionleadershipcouncil.co..co.uk
4. Korea Express Corporation, *Smart Construction Global Insight: Construction Automation and Robotics*, Vol. 1, Center for Smart Construction Technology, Korea Express Corporation, Seoul, Korea, August 2021.
5. Taher, G. Industrial Revolution 4.0 in the Construction Industry: Challenges and Opportunities, *Management Studies and Economic Systems* (MSES), 6 (3/4), Summer & Autumn 2021, pp. 109-127.
6. Forcael, E.F., Ferrari, I., Opazo-Vega, A., and Pulido-Arcas, J.A. Construction 4.0: A Literature Review, *Sustainability* MDPI, 2020, 12,9755.

7. Sawhney, A., Riley, M., Irizarry, J., and Perez, C.T. A Proposed Framework for Construction 4.0 Based on Review of Literature, *EPiC Series in Built Environment,* Associated Schools of Construction Proceedings of the 56th annual international Conference, Volume 1, 2020, pp. 301-309.
8. DroneDeploy, The Rise of Drones in Construction, June 2018, www.dronedeply.com/blog/rise-drones-construction (accessed on January 2023)
9. Allied Market Research, Commercial Drones Market Expected to Reach $21.69 Billion by 2030, www.alliedmarketresearch.com/press-release/commencial-drone-market.html (accessed on 24 November 2022)
10. Adhikary, R. and Parikh, K. Drone Mapping Versus Terrestrial Laser Scanning for Building Mapping and Assessment, *Journal of Remote Sensing & GIS*, Vol. 10, Iss.3, No:1000283, 1-4
11. Ock, J.H. Testing As-Built Quality of Free-Form Panels: Lessons Learned from a Case Study and Mock-up Panel Tests, *Applied Science*, MDPI, Appl. Sci. 2021, 11, 1439. https://doi.org/10.3390/app11041439
12. Kwen, S.H.; Shim, H.W.; Jang, H.S.; Ock, J.H. A Fundamental Study on the Comparison of As-Planned with As-Built of Free-form Building Skins Using Laser Scanning Technology, *J. Comput. Des. Eng.* 2011, 2, 126–136.
13. www.linkedin.com/pulse/from-uav-bim-how-data-fits-scan-workflow-himani-shah/ From UAV to BIM – How UAV Data Fits into the Scan to BIM Workflow (accessed on January 14, 2023)
14. Rizo-Maestre, C., González-Avilés, A., Galiano-Garrigós, A., Andújar-Montoya, M.D., and Puchol-García, J.A. UAV + BIM: Incorporation of Photogrammetric Techniques in Architectural Projects with Building Information Modeling Versus Classical Work Processes, *Remote Sensing*, MDPI, 2020, 12, 2329; doi:10.3390/rs12142329
15. Park, K.J. and Ock, J.H. Structuring a BIM Service Scoping, Tendering, Executing, and Wrapping-Up (STEW) Guide for Public Owners, *Appl. Sci.*, MDPI, 2022, 12, 3275. https://doi.org/10.3390/app12073275
16. CONECTech Lab – The Home for Construction 4.0 Technology Education and Research (gatech.edu)
17. Overview of the Curriculum Development Process, Curriculum development Guide: Population Education for non-Formal Education programs of Out-of-School Rural Youth (fao.org)
18. Howard, J. *Curriculum Development*, Center for the Advancement of Teaching and Learning, Elon University, Summer, 2007.
19. Krueger, R.A. *Designing and Conducting Focus Group Interviews,* University of Minnesota, USA, October 2002.
20. Schwab, K. The Fourth Industrial Revolution, *The World Economic Forum*, 2016.
21. Herman, M., Pentek, T., and Otto, B. Design Principles for Industrie 4.0 Scenarios, *49th Hawaii International Conference on System Science (HICSS),* 2016 March 3928-3937, http://doi.org/10.1109/HICSS.2016.488
22. Kagermann, H., Wahlster, W., and Helbig, J. Recommendations for Implementing the Strategic Initiative INDUSTRIE 4.0 – Final Report of Industrie 4.0 Working Group. In *Industrie. Frankfurt*, 2013.
23. Lasi, H., Fettke, P., Kemper, H.-G., Feld, T., Hoffman, M. Industry 4.0 *Bus. Inf. Syst.Eng.* 2014, 6, 239-242.
24. Berger, R. *Digitization in the Construction Industry: Building Europe's Road to "Construction 4.0";* Roland Berger GMBH: Munich, Germany, 2016.
25. Garcia de Soto B., Agusti-Juan I., Joss S. and Hunhevicz J. Implications of Construction 4.0 to the Workforce and Organizational Structure, *The International Journal of Construction Management*, 2019, 1-13.
26. Maiellaro, N., Zonno, M., and Lavalle, P. Laser Scanner and Camera-equipped UAV Architectural Surveys, The International Archives of the Photogrammetry, *Remote Sensing and Spatial Information Sciences*, 2015, Vol. XL-5/W4, 381-686, 3D Virtual Reconstruction and Visualization of Complex Architectures, Avila, Spain, 25-27.
27. Mader, D., Blascow, R., Westfeld, P., and Mass, H.-G. UAV-based Acquisition of 3D Point Cloud – A Comparison of a Low Cost Laser Scanner and SFM-Tools, The International Archives of the Photogrammetry, *Remote Sensing and Spatial Information Sciences,* Vol. XL-3/W3, 335-341, ISPRS Geospatial Week 2015, 28 September – 03 October 2015, La Grande Motte, France.
28. AL-Tahir, R. Integrating UAV into Geomatics Curriculum. In The International Archives of the Photogrammetry, *Proceedings of the Remote Sensing and Spatial Information Sciences,* Toronto, ON, Canada, 30 August–2 September 2015; Copernicus Publications: Toronto, ON, Canada, 2015. 5.
29. Bolick, M.M., Mikhailova, E.A., Post, C.J. Teaching Innovation in STEM Education Using an Unmanned Aerial Vehicle (UAV), *Education Science,* MDPI, 2022, 12, 224.
30. He, Y.; Lu, H.; Song, Y.; Liu, L. Design and implementation of virtual simulation experiment system for acquisition and production of UAV real-scene 3D data. *In Proceedings of the IEEE 4th International Conference on Automation, Electronics, and Electrical Engineering,* Shenyang, China, 19–21 November 2021.
31. Sanson, J.S. Drone Use in Construction Industry Leads to Integration into the Current Civil and Construction Engineering Technology Curriculum, Session ETD 455, *Proceedings of the 2019 Conference for Industry and Education Collaboration,* American Society of Engineering Education, 2019.
32. Kandrot, S. and Holloway, P. Applications of Drone Technology for Sustainable Development of the Coastal Zone: A Literature Review, Work Package 2: Technological Innovation for Sustainable Development Deliverable T2.1.1: Project report, *Sustainable Resilient Coast,* July 2020.

 doi:10.20944/preprints202304.1033.v1

33. Graham, S. *What is Sustainable Construction?* Holcim Foundation, 2022
34. Bigrentz, *Sustainable Construction: Methods and Benefits,* February, 2020
35. Miguel, R.S. Drone Technology Makes Sustainable Construction Possible, *The American Surveyor,* December 2021.
36. Jackson, C. What is Sustainable Construction? *Construction 21 International,* December 2021.
37. Balasubramanian, S., Shukla, V., Islam, N., and Manghat, S. *Construction Industry 4.0 and Sustainability: An Enbling Framework,* Term-21-0482.R1, University of Exeter, http://handle.net/10871/126992.
38. Lee, G.; Kim, S.W. Case Study of Mass Customization of Double Curved Metal Façade Panels Using a New Hybrid Sheet Metal Processing Technique, *J. Constr. Eng. Mgmt.* ASCE, 2012, 11, 1322–1330.
39. Ministry of Land, Infrastructure and Transport (MOLIT). *Year 2021 Public Announcement of the Contractors' Construction Capacity Evaluation.* Available online: http://www.molit.go.kr (accessed on 28 November 2020).
40. Alonso, S.H.; Rubio, J.I.M.; Martin, J.F.; Fernandez, J.J.G. Comparing Time-of-Flight and Phase Shift. The Survey of the Royal Pantheon in the Basilica of San Isidoro. International Archives of the Photogrammetry, *Remote Sensing and Spatial Information Sciences,* 38-5/W16. In Proceedings of the ISPRS Trento 2011 Workshop, Trento, Italy, 2–4 March 2011; pp. 377–385.
41. http://www.dji.com/product/phantom-4, Phantom 4 User Manual, DJI (accessed on 15 November, 2022).
42. http://www.dji.com/product/mavic-2, Mavic 2 User Manual, DJI (accessed on 20 November, 2022).
43. http://law.go.kr Korean Aviation Safety Act (accessed on 10 November, 2022).
44. Zhang, C., Arditi, D, and Liu, P. Integrating Laser Scanning Technology into a Construction Engineering and Management Curriculum, *2021 ASEE Annual Conference,* Paper ID #33992, American Society for Engineering Education, 26-29 July, 2021.
45. Shanbari, H.A., Blinn, N.M, and Issa, R.R. Laser Scanning Technology and BIM in Construction Management Education, *Journal of Information Technology*, ITcon, 2016, Vol.21, 204-217.
46. *Pix4D Mapper 4.1 User Manual,* Pix4D, 2019, Switzerland.
47. Williams, K.W. *A Summary of Unmanned Aircraft Accident/Incident Data: Human Factors Implications,* Civil Aerospace Medical Institute, Federal Aviation Administration, Oklahoma City, OK 73125 December 2004.
48. Top four reasons for drone accidents | QBE AU (accessed on 13 January, 2023)
49. *Lab Manual for Pix4D Mapper*, First Edition, Pix4D, Switzerland, June 2019.
50. Deloitte. U*nmanned Aircraft Systems (UAS) Risk Management: Thriving Amid Emerging Threats and Opportunities*, November 2018.
51. Kim, S.J. and Irizarry, J. Human Performance in UAS Operations in Construction and Infrastructure Environments, *Journal of Management in Engineering,* ASCE, 2019, 35(6), 04019026.
52. Doroftei, D., Cubber, G.D., and Smet, H. Assessing Human Factors for Drone Operations in a Simulation Environment, Human Factors in Robots, *Drones and Unmanned Systems,* AHFE International, 2022, Vol.57, 122-129. http://doi.org/10.54941/ahfe1002319.
53. Skyepack, *Curriculum Development: Complete Overview & 6 Steps,* September 2020, www.skyepack.com