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Research Paper

Exploratory Study on the Process and Checklist Items for Construction Safety Inspection Utilizing Drones

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ABSTRACT

The focus of this research was to devise a conceptual methodology for drone usage and to assess the viability of safety checklist items specific to drone application in safety oversight. The appraisal was grounded in a focus group interview involving professionals from construction management and safety fields. The proposed process was segmented into four stages: 1) pre-flight phase for flight plan development, 2) drone flight phase for safety condition inspection utilizing checklist items, 3) post-flight phase for visual asset analysis, and 4) documentation and management phase. Furthermore, the research scrutinized the applicability of 32 distinct safety checklist items for drone operations. The primary aim of this investigation was to probe the possible deployment of drones as part of construction safety inspections at work sites. However, it bears mentioning that subsequent research should strive to gather a more extensive sample size through questionnaire surveys, thereby facilitating quantitative analysis. Administering such surveys would yield more comprehensive data compared to a focus group interview, which was constrained by a limited participant count. In summation, this study lays a foundational groundwork for understanding the potential advantages and challenges associated with integrating drones into construction safety management.

Keywords : drone, construction safety, focus group interview, process development, safety management

1. Introduction

Recently, the construction industry has faced various difficulties in performing safety management, as construction works in various fields are often entangled in an extremely complicated manner. In fact, in 2021, a total of 5248 construction accidents was reported in Korea, with the total number of deaths being 235. Among them, accidents caused by falls accounted for 53.6% of all fatal accidents, which shows the importance of safety management at construction sites[1].

Meanwhile, unmanned aerial vehicles(UAVs)—commonly called drones—were previously used for military purposes, but they are now being increasingly used in various fields such as leisure, agriculture, and broadcasting construction due to the emergence of the 4th industrial revolution. In particular, UAVs can be used to deliver visual and contextual information about the environment to the management personnel at construction sites[2,3].

Implementing safety management at a construction site can sometimes be difficult for people to approach, or it can take a lot of time. Many studies are examining various functions of UAVs, as they can be used not only in the construction stage but

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also in safety management, where they show high efficiency[4]. However, there is a lack of research into the process for using drones in field safety management. Therefore, this study aims to establish a strategy for promoting the use of drones in construction site safety management[5].

Literature review according to the Enforcement Regulations of the Construction Technology Promotion Act, self-safety inspections(daily/monthly) at construction sites must be conducted according to the safety inspection table of the construction management plan under the direction of the safety management manager for each field[6]. Moreover, the safety inspection period of the vulnerable period should be divided into inspections occurring during the thawing season, rainy season, and winter season, and safety inspections should be conducted using an appropriate safety checklist. In small and medium-sized construction sites, there are vulnerabilities associated with scaffolding and work platforms with high risk of accidents such as falling, overturning, and falling due to poor financial conditions. Accordingly, research has shown that government-level project budget expansion and the reorganization of temporary scaffolding safety guidelines to ensure safety would help reduce the overall accident rate at construction sites[7]. As having a safety management system is the most urgent task for all construction sites, a system for sharing safety knowledge and information with all workers as well as managers of professional construction companies should be established[5]. This presents institutional improvement measures in construction site safety management.

Drones can be applied to a safety management system by flying around the jobsite and delivering safety-related information[8]. The laws related to drones in the United States are set by the Federal Aviation Administration(FAA). The FAA aims to build a safe and sustainable aviation system for drones and flights by stipulating duties related to aircraft, air traffic, airports, pilots, and space, and to create jobs, according to Part 107 and FAADroneZone[9]. Song and Cho[10] tried to integrate drones into a safety management plan by collecting visual data through the use of multi-purpose sensors attached to the drone. A study provided an overview of how the drone can be integrated into the safety management by observing the critical factors affecting the drone uses[11]. Another study developed a game engine-based construction safety inspection system by using UAV and deep learning-based object recognition[12]. Although various drone-based safety management utilization studies are actively being conducted, studies on the usability of processes and checklists are still limited. Therefore, the present study aims to develop the safety inspection process at construction sites and investigate the applicability of the safety inspection checklist items for integrating with drones into construction safety management.

2. Research Methodology

The main goal of this study is to provide a conceptual strategy for integrating drones into construction safety management. To end up this, this study conducted a focus group interview with construction industry professionals. A Focus group interview is a very effective method to ask the perceptions of a small group consisting of professionals from the same domains and disseminate the quantitative outcomes based on the discussion among the group members[13]. Based on the literature review, the question to discuss were initially developed. It consists of two sections: 1) process design and 2) applicability of current safety inspection checklist items. The interview was conducted on October 12, 2022, to confirm the applicability of drones in safety management. Experts were asked about their personal information and additional information required when using a drone for each process was freely described in the drone-based construction safety management process part. In the

drone applicability part for each construction safety management checklist item, the suitability of the drone for each process was measured on a Likert 5-point scale. Figure 1 describes the focus group interview process in this study.

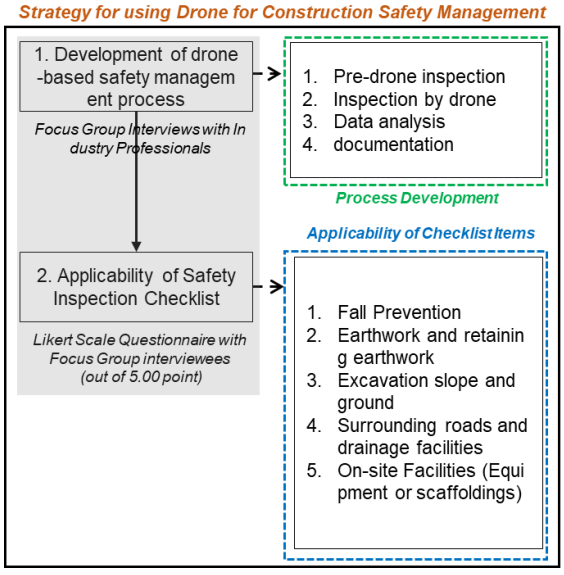

Figure 1. Focus group interview

This study's survey subjects were five professionals with significant experience in safety management at construction sites. The background of the interviewees is described in Table 1. Four out of the five interviewees were male(80%), and their ages ranged from the 30s to 60s. Most of the duties they performed were construction and safety management, and their experience ranged from less than 5 years to more than 21 years.

Table 1. Participants in the focus group interview

Background of Interviewees		Ratio
Gender	Male	80%
	Female	20%
Occupation	Project Engineer	20%
	Project Manager	20%
	Safety Coordinator	60%
Work Experience	Less than five years	40%
	Five to 10 years	20%
	11 to 20 years	20%
	More than 21 years	20%

3. Conceptual Process for Drone-based Construction Safety Management

In this study, the safety management process was organized through the case of construction site safety management using a drone. 1) Prior to safety inspection, safety policies and goals are set. A drone flight team is formed, the scope of team

members' responsibilities is set, and daily, weekly, and monthly flight goals as well as take-off and landing locations are set. Then, the flight is prepared using the identified checklist items. 2) In the safety inspection implementation stage, safety monitoring is conducted by collecting visual data on safety concerns. During this process, in-flight communication takes place between the operator, observation point, and project engineer. Based on this monitoring, audits are conducted, and corrective actions are implemented based on immediate feedback on unsafe situations that have occurred. 3) After the safety inspection is performed, based on the visual data collected from the drone flight, the safety status is analyzed using the drone-integrated safety inspection checklist items that meet occupational safety and health association(OSHA) standards. After recording data on the hours of flight, images, video recordings, data analysis, and decisions are documented. Figure 2 shows the drone-based safety management process established by synthesizing overseas cases and expert interviews.

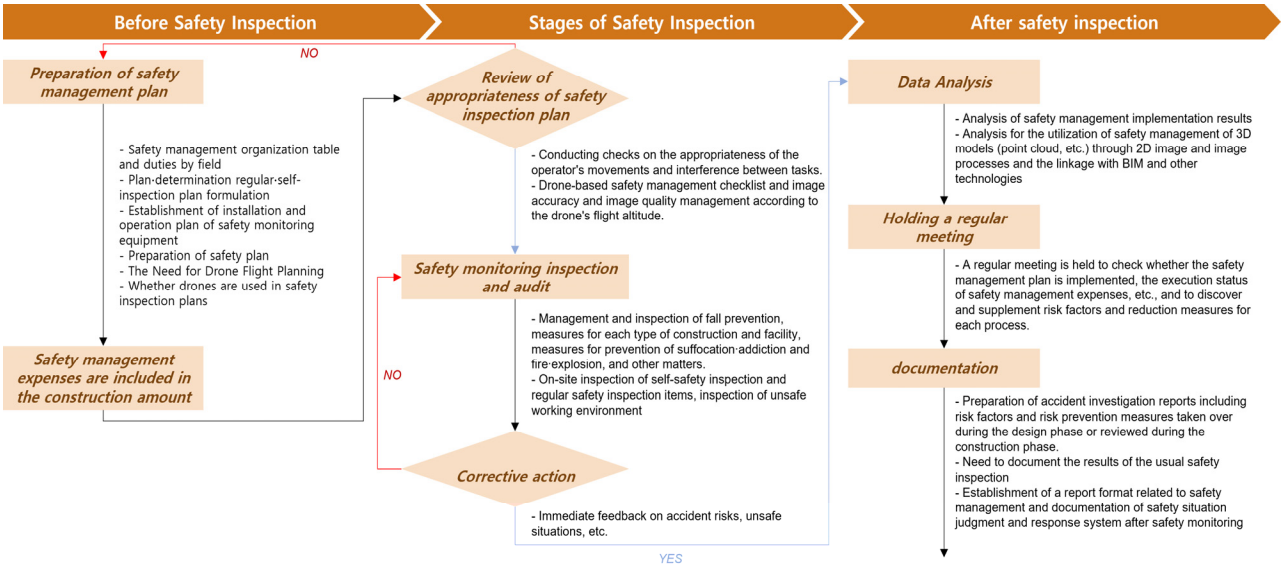

Figure 2. A conceptual safety inspection process by integrating UAV

3.1 Pre-Safety inspection step

The safety management organization table and duties for each field are planned and determined, and regular and self-safety inspection plans and safety monitoring equipment installation and operation plans are established. In the overseas safety management process using the drone, a drone flight team is formed before the safety inspection, job planning for safety management managers in each sector is performed, drone flight goals are set, take-off and landing locations are set, and checklist items are determined before the flight. Currently, it is necessary to plan a safety management organization for construction work and establish a plan for installing and operating safety monitoring equipment. Therefore, drone-based safety checklist items must be determined by adding flight team composition, team members and job plans, and setting flight goals before drone flights. Construction experts who participated in the interviews before the safety inspection stage responded that when the drone was applied to the details of the existing safety management process, it was necessary to decide whether to use a drone and establish a drone flight plan in the safety inspection plan establishment stage.

3.2 Safety inspection step

In the safety inspection phase, fall prevention, measures for each type of construction and facility, measures to prevent suffocation/poisoning, fire/explosion, etc. are managed and inspected, and on-site inspections are conducted for self-safety inspection and regular safety inspection items. Safety helmets and unsafe working environments are also inspected to ensure the safety of construction sites. On-site monitoring is typically conducted using drones to inspect the site for self-safety inspection and regular safety inspection items. Drones are also used to provide immediate feedback by enabling communication between the constructor, the owner, and the project manager. In the safety inspection stage, on-site monitoring using drones enable fall prevention, measurements according to construction type and facility, evaluations of safety helmets, and inspections of unsafe working environments. Further, since a site can be monitored in real-time using a drone, it can enable efficient communication and immediate feedback between the constructor, the owner, and the project manager, unlike before, when communication between the constructor and the owner was slow.

3.3 Visual data analysis step

In the process of data analysis in the current safety management, whether the safety management plan has been implemented and the execution status of safety management expenses are checked, risk factors and reduction measures are identified for each process, and regular meetings are held to ensure security. In the data analysis process using drones, the visual data collected by drone flight is processed and the safety status is analyzed using the drone-integrated safety inspection checklist items that meet OSHA standards. Then, using this analyzed data, safety issues are discussed and solutions to the problems are found. In general, when conducting a safety inspection on site, problematic situations can only be identified by and discussed with a limited number of people and at a limited time. However, since the visual data collected through drone flight can be used to identify and discuss problems with many people in high definition regardless of the location and size of the site, drone flight can be used to find solutions more accurately and efficiently. In the safety inspection implementation stage, in the existing 'safety inspection plan adequacy review' stage, which does not use drones, experts conducted self-safety inspections such as fall prevention, measures by construction type and facility, and regular safety inspections. They responded that it was necessary to check the appropriateness of the movement between drone and workers as well as the indirectness between tasks when drones were applied, although inspections were only conducted on the work environment that had not yet been accessed. It was also explained that it was necessary to create a drone-based safety management checklist in addition to the self-inspection checklist, and to prepare standards for image accuracy and image quality according to the flight altitude of the drone.

3.4 Documentation step

In the current safety management documentation process, the risk factors, risks, and reduction measures taken over from the design stage or reviewed during the construction stage are collected and stored in the design document. In the case of a construction accident site, an accident investigation report that includes the accident summary, cause, and measures is prepared to prevent a recurrence. In the process of culturalization abroad, data on flight time, number of images, and video recording time collected by drone flights are recorded and documented. In the case of introducing drones to construction site

safety management, it is necessary to additionally process and analyze visual data collected by drone flight. Therefore, in addition to the process of collecting safety management documents and storing them as part of design documents, the visual data collected by drone flights are processed and analyzed for inclusion in safety management documents.

In the post-safety inspection stage, construction experts can use the vast amount of 2D images and 3D models collected through the image process when drones are applied to safety inspections for safety management and the possibility of linking with other technologies such as BIM. The need for careful consideration was mentioned in the interviews, and after safety monitoring using drones, it was answered that it was necessary to think about the form of report contents related to safety management and documenting the safety situation judgment and response system.

4. Applicability of Safety Inspection Checklist Items

Based on the safety inspection checklist currently used in Korea, a questionnaire was conducted using a 5-point scale to confirm and analyze the possibility of applying drones to safety inspection, and the collected results were presented in the form of average values. In the fall prevention process among the safety inspection checklist, the overall average was 3.93, which is generally considered to be highly applicable to drones. The highest items were safety passage secured, fall prevention during steel framework, fall prevention during roof work, and personal protective equipment for fall prevention, all with average values of 4.20, while the lowest item was falling prevention, with an average value of 3.00(Table 2).

Table 2. Applicability of the fall prevention safety inspection checklist

Fall prevention	Score(out of 5.0)
Whether a safe passage is secured	4.20
Fall prevention from scaffolding	3.80
Fall prevention during steel framework	4.20
Prevention of falls on openings	4.20
Whether or not personal protective equipment for fall prevention is worn	3.00
Overall average	4.20

Among the safety inspection checklist, the safety inspection process for earthworks and earth retaining beams(Table 3) shows the highest applicability among all processes, with an overall average value of 3.97. The items inspecting whether the inflow of surface water has been prevented, whether assembly drawings have been drawn up, and whether or not the work order has been followed show the highest applicability among all items, all with averages of 4.60, while the item checking whether or not the retaining pipe is installed shows the lowest applicability, with an average of 3.02.

Table 3. Applicability of the earthwork and retaining earthwork safety inspection checklist

Earthwork and retaining earthwork	Score(out of 5.0)
Inspection of abnormalities in the surrounding ground	4.20
Investigation of underground facilities	2.40
Review and comparison of design documents	3.20
Check compliance with proper gradient	4.20

Table 3. Applicability of the earthwork and retaining earthwork safety inspection checklist(Continued)

Earthwork and retaining earthwork	Score(out of 5.0)
Inspection of gutter and drainage in the construction work area	4.20
Inspection of surface water inflow prevention measures	4.60
Arrangement and inspection of construction equipment such as excavators and dumpers	3.80
Drawing up assembly drawings and checking compliance with work order	4.60
Site survey and inspection	3.80
Inspection of application of safety measures for supports(supports, wales, anchors, etc.)	4.60
Inspection of whether backside cavity filling and soil leakage prevention measures are implemented	4.40
Check whether measurement management is implemented and whether measurement yield, cycle, and standard value are exceeded	4.00
Inspection of earth retaining pipe installation confirmation	3.20
Overall average	3.97

Table 4 shows the applicability of the excavation slope and ground safety inspection process, which had an overall average of 3.95, which is not the highest among all processes; however, all items scored average values of 3.40 or higher, thus showing the overall high possibility of drone application. The items showing the highest applicability had an average of 4.60, which were the inspection of installation conditions of temporary facilities such as scaffolding, formwork, and staging, while the item with the lowest applicability had an average of 3.40, which was the review of the adequacy of the excavation slope ground condition.

Table 4. Applicability of the excavation slope and ground safety inspection checklist

Excavation slope and ground safety inspection	Score(out of 5.0)
Review of adequacy of excavation slope ground conditions	3.40
Inspection for subsidence, cracks and deformation	3.80
Inspection of measures to prevent overturning and falling of vehicles and construction machinery	4.00
Inspection of abnormal installation conditions of temporary facilities such as scaffolding, formwork, and shores	4.60
Overall average	3.95

Table 5 describes the safety inspection processes, such as of surrounding roads and drainage facilities, which showed the lowest applicability among all processes with an overall average value of 3.27. The item for reviewing the adequacy of the condition of the temporary road for construction showed the highest applicability with an average value of 4.40, and the item for checking the urban subway construction showed an average value of 2.60, which was the lowest drone applicability among the entire process.

Table 5. Applicability of the safety inspection checklist surrounding roads and drainage facilities

Safety inspection of surrounding roads and drainage facilities	Score(out of 5.0)
Examination of the adequacy of the condition of temporary roads for construction	4.40
Confirmation of downtown subway construction	2.60
Review of the adequacy of protection measures for underground facilities	2.80
Overall average	3.27

Table 6 also shows the safety inspection process for on-site facilities, such as scaffolding and tower cranes, which can be seen to have an overall average of 3.97, which is the highest applicability among all processes, along with the safety inspection process for earthworks and retaining supports. The item checking compliance with the tower crane work restriction standards during strong winds showed the highest applicability, with an average score of 4.40, while the item for pre-safety check in preparation for strong winds showed the lowest applicability with a score of 3.60.

Table 6. Applicability of the safety inspection checklist for on-site facilities such as scaffolding and tower cranes

Safety inspection of on-site facilities such as scaffolding and tower cranes	Score(out of 5.0)
Inspect scaffold assembly for abnormalities	4.20
Check scaffolding materials for damage and attachment or jamming	4.00
Checking the looseness of scaffolding connections or connections	3.80
Check for damage or corrosion of connecting materials and connecting hardware	3.80
Check the settlement, deformation/displacement or shaking of scaffolding columns	4.00
Confirmation of compliance with tower crane work restriction standards in case of strong winds	4.40
Preliminary safety check in preparation for strong winds	3.60
Overall average	3.97

5. Conclusion

This study reviewed safety management status and systems and benchmarked overseas safety management cases in an attempt to establish processes and strategies to promote the use of highly efficient drones in construction site safety management, which is currently either difficult for people to access or takes a lot of time. Based on data from previous studies, interviews were conducted with experts, and a strategy for drone use safety management was ultimately established. Applying drones in the field of construction safety management has the positive impact of allowing safety inspection managers to check. in real-time. the statuses of places that are difficult to check directly, and a frontal view of the construction site can be viewed from the air, thus allowing the overall construction site to be seen. The experts stated an opinion that the safety of the layout can be easily observed using a drone, and that the effectiveness of the safety inspection can be secured because the safety of the layout can be easily observed and confirmed even if a person does not climb directly to inspect the upper part of the building.

Problems that may be caused by the application of drones include the need for additional costs and professional training for drone use, errors in collected data, and accidents caused by drones falling during flight. Moreover, accidents due to the fall of drones must be considered, and when making judgments solely according to photographs, the manager's subjective judgment can be large and rather dependent on 2D/3D data, so there is a problem in that the reliability of the analysis results can be lowered. As an improvement plan for problems that may occur with the application of drones, there is a need for a specific manual for each process to secure the effectiveness of drones, as well as the connection of artificial intelligence or other technologies(BIM, AR/VR robots, etc.). With this, it is expected that more objective data analysis, result derivation, and automation of documentation work will be needed.

Through this study, based on the safety checklist used in Korea, as a result of a focus group interview to confirm the applicability of drones to safety inspection, drones were confirmed to have high applicability in almost all safety inspection

items. In this study, the drone-based construction safety inspection process using drones were developed, and the applicability of the safety inspection checklist with the use of drone was analyzed through the focus group interview. However, this study has very limited number of focus groups, hence the outcome of this study is on the very preliminary step. The further studies should distribute to a well-designed questionnaire survey to evaluate the applicability and usability of drones for construction safety inspections quantitatively. Despite of this limitation, this study successfully provided the overview of strategy to use the drones for construction safety management systems. It is expected that the outcomes of this study can serve as the fundamental for implementing the UAV into the construction safety management at the actual jobsite environment. Also, this study also found that the flight height of the UAV and the angles of the camera-equipped at the platform have significant effects on the quality of visual assets and observing the checklist items. Therefore, further studies might be able to investigate how the flight plans of drones can be optimized in order to inspect the checklist items efficiently on the pre-flight steps.

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