Automated building occupancy authorization using BIM and UAV-based spatial information: photogrammetric reverse engineering

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ABSTRACT
At present, due to the use of manual, rather than automated measurements, the inspection for building occupancy authorization lacks objectivity. Seeking to improve this situation, in this study, we used unmanned aerial vehicle for automated inspection for building occupancy authorization. Theoretical considerations about building occupancy authorization and the trend of UAV technology were accomplished. Furthermore, reverse engineering, including digital photography, network RTK-VRS surveying, and post-processing data, was conducted. The obtained spatial information was used for building occupancy inspection authorization in a BIM platform, and the effectiveness and applicability of UAV-based inspection was analyzed. The results of this study demonstrate that UAV-based automated inspection can reduce error rate in on-site measurement, conduct complete enumeration survey of the entire range of building, and collect data ensuring objectivity of the inspection due to authentic accuracy and effectiveness.

1. Introduction
In the current building occupancy authorization system in Korea, due to the use of manual rather than automated measurements, the inspection for building occupancy authorization lacks objectivity. Seeking to improve this situation, in this study, we used unmanned aerial vehicle for automated inspection for building occupancy authorization. Theoretical considerations about building occupancy authorization and the trend of UAV technology were accomplished. Furthermore, reverse engineering, including digital photography, network RTK-VRS surveying, and post-processing data, was conducted. The obtained spatial information was used for building occupancy inspection authorization in a BIM platform, and the effectiveness and applicability of UAV-based inspection was analyzed. The results of this study demonstrate that UAV-based automated inspection can reduce error rate in on-site measurement, conduct complete enumeration survey of the entire range of building, and collect data ensuring objectivity of the inspection due to authentic accuracy and effectiveness.

Our aim is to enhance the objectivity of the inspection, thereby contributing to the original intent of the system, ie protecting the public safety and property. Furthermore, as part of the research on applying ICT to ACE, this paper aims to establish whether inspection for building occupancy authorization can be automated by reverse engineering approaches, including digital photography, network RTK-VRS surveying, post-processing data, establishing BIM-UAV based spatial information and building occupancy inspection authorization in a BIM platform using spatial information. Figure 1 shows the flow of the research.

2. Consideration for automated inspection for occupancy authorization
Buildings must be designed, constructed, and supervised in compliance with the procedures and codes stipulated in the Building Act. Figure 2 explains the entire process of building occupancy authorization in Korea. On-site inspection for building occupancy authorization is a manual measurement method where an operator moves around the building carrying equipment. Accordingly, it is impossible not to generate errors, and there is a limit to examining the entire building moving around. The lack of tangible evidence to prove objectivity and legality in inspection results leads to rampant occupancy authorization of illegal structures. Other negative consequences include the loss of...
architectural ethics due to connivance of illegal matters caused by corruption in the process of getting an approval of use, safety accidents in illegal structures, and ill-gotten profits to particular individuals.

Currently, UAV and 3D scanner are widely used in the AEC industry for automated measurement and on-site surveying. Table 1 outlines the pros and cons of using UAV-based photogrammetry and 3D laser scanning technologies. As outlined in Table 1, compared to manual measurement and 3D scanning, the UAV-based photogrammetry is more suitable for the experiment on the automated inspection for building occupancy authorization, particularly in terms of cost-effectiveness and efficiency. According to previous research, the advantages of UAV are as follows. First, unlike photos taken by manned aircrafts or satellites, UAV-based aerial photogrammetry accelerates data gathering and monitoring tasks (Unger, Reich, and Heipke 2014; Kim et al. 2014; Kim, Yu, Park, and Ha 2008). Second, UAV-based aerial photogrammetry has advantages over manned aircrafts, artificial satellites, and 3D scanners in terms of convenience and cost-effectiveness (Colomina et al. 2008; Choi 2014a; Lee, Choi, and Joh 2015). Third, UAV features low-altitude photogrammetry and gathers high-resolution image information and spatial information securing the position accuracy and spatial resolution (Haala, Cramer, and Rothermel 2013; Cho et al. 2014; Lee, Hong, and Lee 2016). In summary, compared to the established surveying method, UAV is fast, convenient, accurate, and interoperable.

Based on the aforementioned theoretical considerations, in this study, 9 items of outdoor inspections were derived for automated inspection for occupancy authorization using UAV-based photogrammetry; these items were expected to exert the greatest effects on the improvement of the on-site inspection. In addition, two further items, ie the building coverage ratio (a ratio of a building area to a lot area) and the open space ratio (a ratio of total open space to...
3. UAV application process for automated inspection for occupancy authorization

A series of experiments were conducted to determine the viability of the UAV-based automated inspection for occupancy authorization. The experiment followed the following procedure: 1. Lot Selection & Condition Setting; 2. UAV-based Spatial Information Generation; 3. Analysis of Results, Comparative Verification, & Effectiveness Analysis. To control the variables, the UAV-based automated inspection for occupancy authorization was postulated to be reliable based on the literature. In addition, the permitted drawings and documents were set as the control group for the experiment, while their objectivity was posited for the comparative analysis. Based on Table 2, random expected values were set for inapplicable regulations based on building sizes and ordinances in order to determine if the inspection would be viable; relevant criteria were set by modifying the specifics to implement a comparable inspection. The building selected for the purpose of this study was a 122-m² sports facility completed in 2016 in K National University in Korea. As the selected target site was located in an educational and research institution, it had no separate cadastral line, such as the reference building line, the lot boundary, and the road lines. Therefore, a new cadastral boundary was set by referencing the natural boundary points, the permitted site plan, and the 1:1000 GRS80 ortho-image. To create the spatial information of the building, its high-resolution images were first captured by the UAV-based low-altitude photogrammetry. The UAV used in the research was a ‘DJI Inspire 1 v2’ fitted with a 12.4M resolution digital camera for the low-altitude photogrammetry. The UAV was set to fly at the height of 10m and 15m above the target building at the speed of 2m/s. The overlap and sidelpap were 80% each. Next, the position accuracy was secured by calibrating the ground reference point using the Network VRS-RTK GPS measurement. ITRF 2000 Korea East Belt TM was used as the coordinate system. Finally, the images gathered by the UAV were post-processed to obtain spatial information that ensured a certain spatial resolution (Ground Sampling Distance, GSD). Pix4D mapper was used for the entire post-processing. Based on the data a lot area), were also included. The enforcement ordinance of the Building Act was analyzed to determine the methods of inspecting each of the 11 items (see Table 2). The specifics listed in Table 2 pertain to the enforcement ordinance of the Building Act and Daegu City’s Building Ordinance.

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with the position accuracy secured, the point cloud and 3D mesh model were created. Then, the data were used to create the spatial information, including ortho-image and DSM (Digital Surface Model). Figure 3 shows the process of generating UAV-based spatial information (Ryu 2016).

The GSD of spatial information, including the post-processed data, the ortho-image, the point cloud data, and the DSM, was less than 1 cm, meaning that a 1-cm object was identifiable per unit pixel. The error rate of 1% per meter met the allowable margin of error (Article 20, Building Act in Korea). Also, the image overlap was over 99%, indicating the lens distortion was sufficiently reliable. Autodesk’s Revit Architecture 2016 (Revit), BIM platform, was used for the inspection for occupancy authorization based on spatial information. The first reason for conducting the inspection in the BIM environment was that BIM, an integrated information platform, can put all architectural information on an object-oriented model. Second, it makes it possible to easily collaborate with multiple decision makers by exchanging information about buildings through interoperability. Thirdly, such an information model is very useful for the future, eg building management & maintenance, evacuation simulation, and environmental evaluation. Revit is compatible with CAD files, PDF files, GIF images, and point cloud data. Therefore, the extracted point cloud data, the ortho-images, and the DSM were retrieved to the Revit environment and overlapped with the CAD drawings. Top and cross-sectional views were used to measure the building’s height, length, area, the length of the building lot, and the widths and slopes of streets and roads. Figure 4 shows the process of inspection using UAV-based spatial information.

4. Comparative verification of inspection results and analysis of effectiveness

Table 3 shows the inspection methods and records for occupancy authorization based on the data gained from the previous experiment. The inspection using the data relative to each item and the comparison with the permitted drawings yielded the following results. As for the building line items, compared with the drawings, the measured distance from the road line to the building showed an 8.1-mm error. The error rate was 0.2%, which was within the allowable margin of error (3%) for the recession distance of the building line (Article 20, Building Act). As for the maximum height per street zone and road, the measured height showed an error of 300 mm. The error rate was 7.1%, which was beyond the allowable margin of error for building heights (Article 20, Building Act). Accordingly, an on-site
Table 3. Inspection result report for building occupancy authorization using unmanned aerial vehicle.

| Automated Item | Survey Method Using UAV | Utilization information | Current Situation | After Completion | Remarks |
|----------------|-------------------------|-------------------------|-------------------|-----------------|---------|
|                |                         | **Image (Raster)**      | **Distance (cm)** | **Height (cm)** | **Area (cm²)** |
| 1. Safety Measures Per Lot | 1 | Measurement of the difference between ground level and road level | - | - | ● | - | [ ] Match | [ ] Mismatch | [●] Not applicable | Difference in height: 1254mm |
|                | 2 | Confirmation of installation of wastewater excellence manhole through interview footage and confirming drainage gradient inside the ground | ● | - | - | - | [●] Match | [ ] Mismatch | [ ] Not applicable | Require scrutiny |
|                | 3 | Ground improvement survey through embankment | - | - | - | - | [ ] Match | [ ] Mismatch | [●] Not applicable | Cannot investigate |
|                | 4 | Confirming installation of retaining wall through interview images | ● | - | - | - | [●] Match | [ ] Mismatch | [ ] Not applicable | Require scrutiny |
| 2. Excavation Measures | | Confirming installation of earthwork signs through interview images | ● | - | - | - | [●] Match | [●] Not applicable | Expected to be possible |
| 3. Landscaping per Lot | | Measurement of land area of land area | - | - | - | ● | (% Over | [●] Not applicable | Replace with area measurement |
| 4. Building Line | | Measurement of the distance from the building line to the building, measure the access road width by the length of the road that contacts the earth | - | ● | - | - | [●] Match | [ ] Mismatch | [ ] Not applicable | - |
| 5. Building Restriction by Building Line | | Identification of the presence or absence of violations through interview footage and Measurement of the distance to buildings and building lines of 4.5 m or less | ● | ● | ● | - | [●] Match | [ ] Mismatch | [ ] Not applicable | - |
| 6. Separation Distance from Building Line | | Measurement the distance from the building line to the building | - | ● | - | - | [●] Match | [ ] Mismatch | [ ] Not applicable | - |
| 7. Separation Distance from Adjacent Lot Boundary | | Distance between adjacent borderline and building | - | ● | - | - | [●] Match | [ ] Mismatch | [ ] Not applicable | - |
| 8. Height Limit per Street Zone & Road | | Measurement of height of building facing sidewalks | - | ● | ● | - | [ ] match | [ ] Mismatch | [●] Not applicable | Replace with height measurement |
| 9. Height Limit for Light | | Measurement of the distance in the northward direction from the building, the height of the building in the north direction | - | ● | ● | - | [●] Match | [ ] Mismatch | [●] Not applicable | Replace with height measurement |
| 10. Building Coverage Ratio | | Measurement of building area against the area of the earth | - | - | - | ● | (37.8695)% | [●] Not applicable | Center line cannot be measured |
| 11. Open Space Secured | | Measurement of open area of open space | - | - | - | ● | (% | [●] Not applicable | Replace with area measurement |
inspection or surveying, as well as reviews of data and drawings, was required for a closer inspection to analyze the cause of the error. The area of the building was calculated based on the outermost outline of the exterior finishing, not the central axis. Compared with the drawings, the lot area showed an error rate of 0.5%, which was within the margin of error allowed for the building coverage ratio (Article 20, Building Act), whereas the building area showed an error rate of 3.1%, which warranted a closer inspection.

Overall, among 11 inspection items, the UAV-based spatial information was applicable to 9 items. As for the safety measures for the lot, this item requires expert help. Since there were differences in the results from inspection of the building and the height, length, and area of the lot between the spatial information and drawings, there is a need to verify which information is closer to the on-site measurement results.

Table 4 (see corresponding items’ depiction in Figure 5) analytically compares the errors in the spatial information between the drawings, UAV, and on-site inspection or surveying results. Table 4 shows that the dimensions based on the UAV data are greater than those specified in the drawings. Also, the on-site measurement results are greater than those in drawings. These findings can be attributed to construction errors.

The on-site measurements were closer to the results based on the UAV-based spatial data than those based on the drawings. Therefore, the inspection results based on the spatial information are closer to the dimensions of the actual building. The error difference between the UAV-based spatial information and the on-site measurement results was compared with the allowable margin of error (Article 20, Building Act in Korea). The UAV-based data for automated inspection for the authorization showed the error rates of 3%, 0.5%, and 1% in the distance, building coverage ratio, and floor area ratio, respectively, falling within the statutory allowable margin of error criteria. In addition, both the building height and the length of the flat surface showed an error rate exceeding 2%, meeting the criteria. That is, the exterior information of the building measured based on the spatial information generated by the UAV met the allowable margin of error, which underscores the reliability and accuracy of the information.

Next, Table 5 shows the amount of time spent per construction type for the analysis of effectiveness (Yun et al., 2016). 2.5 hours, 3.5 ~ 9 hours, and 1.5 hours were spent on imaging, image processing, and analysis of results, respectively. As for photogrammetry, the surveying at ground reference points and the aerial photography should take longer in proportion to the size of a building. As for image processing, the time increased with the number of photos, which, in turn, increased with the size of the building, and varies with the quality of results. To acquire a moderate quality and half the size of the original images, approximately 3.5 hours were spent on 100 photos with the original sizes taking 3 ~ 4 times longer.

Except for the different sizes, the spatial resolution and the position accuracy remained identical, which ensured the reliability of the inspection with small-sized outputs. As for the analysis of results, the time spent should not be affected by the increase in the size of a building unless the number of inspection items increases. The analysis of effectiveness indicated it would take 7.5 hours to inspect the building for occupancy authorization based on the UAV-based spatial information; therefore, the output of moderate quality was sufficient for the inspection. According to previous research on the time for inspection agents to conduct the inspection on behalf of municipal offices, the municipal ordinances prescribed 3 ~ 5 days for the inspection, which seemed sufficient for inspecting the outdoor parts of the building and for securing objective data by generating spatial information.

5. Conclusions

This study aimed to improve the objectivity of the inspection for occupancy authorization through automation and exploring the applicability of UAV technology. To this end, we analyzed the viability of automated on-site inspection for the occupancy authorization. We assumed this approach to be easier, faster, and more reliable d the

Table 4. Comparison analysis of error.

| Item                  | Result                  | Error with Actual Measurement |
|-----------------------|-------------------------|------------------------------|
|                       | Drawing | UAV Utilization Data | On-site Actual Measurement | Drawing | UAV Utilization Data | Error Rate |
| Distance from Site Boundary | 3413.3 | 3421.4 | 3418.6 | −5.3 | 2.8 | 0.1%      |
| Building Length L1    | 23650  | 23952  | 23892  | −242 | 60  | 0.3%      |
| Building Length L2    | 5300   | 5401   | 5390   | −90  | 11  | 0.2%      |
| Building Height H1    | 4200   | 4535   | 4488   | −288 | 47  | 1.0%      |
| Building Height H2    | 4200   | 4530   | 4470   | −270 | 60  | 1.3%      |
| Building Area         | 125.3  | 129.4  | 128.8  | −3.5 | 0.6 | 0.5%      |
| Land Area             | 340.6  | 341.7  | -      | 1.7  | 1.7 | 0.5%      |
conventional method, and our results supported this expectation. Specifically, the findings of this study can be summarized as follows.

First, a method of UAV-based automated on-site inspection for building occupancy authorization was previously proposed in a series of reverse engineering approaches, including UAV-based low-altitude photogrammetry, network RTK-VRS surveying, post-processing data, establishing BIM-UAV based spatial information, and building occupancy inspection authorization in a BIM platform using spatial information. Accordingly, in this study, manual inspection was replaced by photogrammetry, which enabled outdoor inspection of the entire building.

Second, the method used in this study proved to be more reliable than the conventional method because of the position reference point and the spatial resolution secured. The intuitive comparison based on the visible and objective spatial information model of the building successfully measured the distance, height, and area. Therefore, this experiment proved that the 11 items for outdoor inspection among the 30 items for the inspection for occupancy authorization are viable for automation. However, this paper is limited to outdoor information for the inspection for occupancy authorization, which warrants further research on the automated inspection of indoor information using other devices including 3D scanners.

Third, as for the efficiency of the UAV-based automated inspection, the spatial information of a building could be acquired simultaneously with the inspection for occupancy authorization. As demonstrated by our results, the proposed method shortens the time to occupancy authorization and meets the allowable margin of error in Korea (Article 20, Building Act), which suggests that the proposed method is reliable and effective. Overall, the UAV-based inspection for occupancy authorization of a building was proved to be effective in practice. The data gained in the process of UAV-based automated on-site inspection for occupancy

**Table 5. Working time.**

| Item capture | Preliminary work | Reviewing satellite maps, checking cameras & VRS units, and UAV maintenance | 1H |
|--------------|------------------|-----------------------------------------------------------------------------|----|
| Pre-flight work | UAV assembly, departure/destination field survey and UAV path setting | 0.5H |
| Ground reference(point) | Setting & VRS-RTK surveying of GRP(GCP) | 0.5H |
| Photogrammetry | Image capturing, checking, and reviewing | 0.5H |
| Sub-total | | 2.5H |
| Image processing | Pre-processing | Downloading raw images, quality check and program setting | 0.5H |
| Final results | Point cloud & 3D mesh | 1H |
| | | | |
| Result analysis | Preliminary work | Output & drawing overlapping | 0.5H |
| Inspection for occupancy authorization | Inspection based on output | 0.5H |
| | Verification by comparison with drawings and preparing inspection records | 0.5H |
| Sub-total | | 3.5H |
| Total | | 7.5H |

**Figure 5.** Comparison items for error analysis.
authorization could be shared for the monitoring in the public sector and could serve as the objective reference data for purposes such as cadastral resurvey, 3D geospatial information generation of country, and ortho-photograph manufacturing.

The proposed method could address further challenges, including moral hazards and safety accidents resulting from the tolerance for unlawful buildings, and create a sound ethos in the building industry. The information reported in this study seems applicable to the cadastral resurvey or the 3D national spatial information implementation in connection with the government policies. In future research, it would be necessary to determine the applicability of the proposed method to a wider range of buildings, e.g., large buildings of complex geometry, high-rise buildings, and even mega structures. This would require classification of buildings based on their size and functions.

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