# Developing A Standard Workflow for Drone Roof Inspections

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**Abstract**

Technology use in construction and facilities management has seen an increase over the past decade with new and emerging technologies of Unmanned Aerial Vehicles (UAV), or "Drones". Drones have been used by Facilities Managers (FM's) in the post occupancy stages to monitor and inspect the condition of various building envelope systems, as a part of protecting the building assets of people, processes and technology. Although there have been previous studies using drone-monitoring on roofs, the evidence of a standardized process is found to be very limited. The goal of this study is to develop and provide a standardized protocol that FM's can utilize in conducting low-slope roof inspections. To develop this framework, a detailed analysis of published literature covering the current processes to inspect building envelope systems was used to develop a structure. Additional steps were identified to add to the existing body of knowledge providing a full sequence standardized workflow specific to low slope roof inspections using drones. As a part of the study, two low-slope roofing inspections with drone technology were conducted using the steps from previous studies joined with the additionally proposed steps to create a formalized workflow.

**Keywords:** drones, workflow, inspections, roof

## 1. Introduction

The usage of drones can be traced back to the 18th century during the Italian war of independence (Rakha and Gorodetsky, 2018). During those past centuries, the military needs were the major funding sources to develop the use and research of unmanned aerial systems (Rakha and Gorodetsky, 2018). However, technological advancements coupled with International Aviation Authorities' easing of restrictions in the 21st century have allowed for the rise of drone usage with public safety, hobbyists, research purposes, commercial and public sectors for various functions (Aydin, 2019).

Drone use has proved to be both time saving and cost effective as the vehicles are able to quickly access hard-to-reach places manually (Falorca and Lanzina, 2020). As a result, many construction partners are developing and utilizing drones to inspect, monitor, and analyze building infrastructure and activities (Duque et al., 2018). The field of civil engineering has also recently gained increasing interest in the usage of drones for bridge inspections (Duque et al., 2018). Chen et al. (2019) report a growing trend of utilizing camera-equipped drones for carrying out building façade inspections. Short-term and long-term forecasts also show that the drones are here to stay as a utilized asset (Aydin, 2019). Marathe (2019) studied drone usage for maintenance and inspections of long pipeline projects and concluded that drones could be effectively employed for this purpose. All these studies show the growing usage of drones in monitoring, inspecting and analysing the built environment envelope systems. Overall, the use of drone technology in the built environment has been conducted by both in-house workers as well as contractor-consultants.

Roofing systems are one of the critical components of the building envelope because it protects the assets within the building including people, place, process, and technology (IFMA). With this responsibility, is in the best interest of the FM, to maintain its high performance. It becomes even more important to utilize technology in the roofing industry since it is one of the sectors where the workforce shortage is severe (Delvinne et al., 2020). Studies by researchers Schweyer (2020) and Bridgers and Johnson (2006) suggest technology adoption is one of the strategic solutions to overcome this shortage.

A considerable amount of research has been carried out to investigate the utilization of drones for inspection in the roofing industry. Bodily (2020) compared the roof inspections carried out by drones and conventional methods and concluded that drones are more efficient in terms of time, cost, value, and safety than the conventional methods. Bodily also outlined that there was a notable and feasible cost-benefit savings by the use of drone inspections over much of the traditional manual inspection methods; however his experience was that facilities managers did not have an organized plan of action to utilize this technology. Gajjar and Burgett (2020) documented the detailed comparison between traditional roofing inspection and drone roofing inspection with respect to low slope roofing. Bown and Miller (2018) studied drone use for sloped roof inspections and presented pros and cons for each step. Between the studies of Bodily and Bown & Miller, it can be deduced that low slope roofs are more common in the commercial/industrial arenas while higher "pitched" roofs are most commonly found in the residential fields. The main differences between these two types of structures seems to be the building size and how that affects the equipment setup and takedown times for inspections. The studies also presented viewpoints for improving the outcome of the drone inspection such as having a standard for conducting the inspections across the industry.

The previous research for low slope roof inspections using drones has primarily been focused on identifying the advantages and disadvantages of using drones for roofing inspections. However, studies to develop standard protocol steps or a standard workflow for better outcomes of drone roofing inspection remain to be explored (Gajjar and Burgett 2020; Rakha and Gorodetsky, 2018). Previous research identified a few studies regarding the steps in using drones for bridge inspections (Duque et al., 2018), building thermography (Entrop and Vasenev, 2017) and building envelope inspections (Rakha and Gorodetsky, 2018).

Duque et al. (2018) conducted a study to compare the benefits of bridge inspections using drones with the traditional method. The study recommended a five stage workflow steps to conduct these inspections. The five steps consisted of bridge information review, site risk assessment, drone pre-flight setup, drone enabled inspection and damage identification. The study concluded that there were some limitations with drone use like weather, high wind, overexposure of camera due to sun or snow, obstacles and areas with the Federal Aviation Administration regulation limit.

Entrop and Vasenev (2017) researched to develop a workflow for surveying building thermography. The said workflow was developed through literature review and a series of test flights. The research defined the objects of interest as the object to be inspected or targeted and identified four major steps to carry out the inspection. The four major steps consisted of planning the initial set-up phase, outlining a safe and secure flight area, accounting for photography requirements – momentarily photos or continuous video collection, and designing a flight path for each element within the object of interest. The study concluded with some limitations as the study was not able to observe all possible external variables, including but not limiting to influence of wind, precipitation and temperature difference in indoors and outdoors.

Rakha and Gorodetsky (2018) conducted a comprehensive literature review of studies which addresses the topic of visualization of heat transfer using infrared imaging and identification of standard steps for drone operated energy audit missions. The steps consisted of pre-flight inspection procedure, during flight anomaly detection and post flight 3D CAD modelling developed through the data gathered by the drone. The study concluded that the steps need to be refined by further testing, replication and gathering empirical evidence for development of standardized workflow.

Bown and Miller (2018) studied the use of drones for conducting steep-slope roof inspections. The goal of the study was to compare the drone inspection with the conventional inspection to mitigate the risk of inspector injury and efficiency involved with steep-sloped roofs. The study chose a three-phase path to conduct the drone roof inspections. Phase 1 included the choice of UAV or drone. Phase 2 explored the image quality and drone flying methods. Phase 3 consisted of approaches to optimize the data captured by drone flight. The study concluded that the drone's inspections can replace manual inspections in most of the cases and that the still images and manual control drone is efficient for large roof areas. Additionally, the study noted that current software frameworks were geared more towards 2-dimensional geographical mapping and would not be serviceable for the angular roofing views that are needed for such inspections. The study recommends the drone inspection as an alternate process for an economical and efficient technology-based method that is safer than conventional methods.

From previous research, it can be included that research on developing workflow steps within roofing industry for low-slope drone inspections is very limited. There was no set protocol found that was being used with any group of contractors, researchers or building owners. Therefore, the goal of this study is to add to the existing body of knowledge by developing and providing the standardized workflow that FM's can utilize. Additionally, this research would include the testing, or flying, of such a sequence to verify that it was both possible and feasible. First, the steps that are published in the literature to inspect building envelope systems were used to develop an initial protocol of how such inspections are carried out. Second, various low-slope roofing inspections using a "DJI Mavic Pro" brand drone were conducted using the protocol from previous studies. Lastly, additional workflow steps were identified to add to the existing body of knowledge providing a full sequence of a more standardized workflow which would be specific to low-slope roof inspections.

## 2. Methodology

As demonstrated in Figure 1, a systematic literature review was conducted to identify previous research on the workflow for drone inspections. A total of eighty-six (86) papers were initially identified based on the abstract of the journal articles. Only peer published articles were selected for the review and literature from thesis, books, online articles and non-peer reviewed articles were excluded. A total of twenty (20) peer-reviewed published journal articles were identified for a full text review to identify the protocol steps for drone inspections. Out of the twenty (20) articles, four (4) journal papers were selected for a qualitative analysis to identify the drone inspection steps. The key steps identified in the qualitative analysis formed the basis of the workflow steps for the drone inspections. The common steps identified through literature review for drone inspections are listed in Table 1. The thirteen (13) keys steps identified were grouped in common themes.

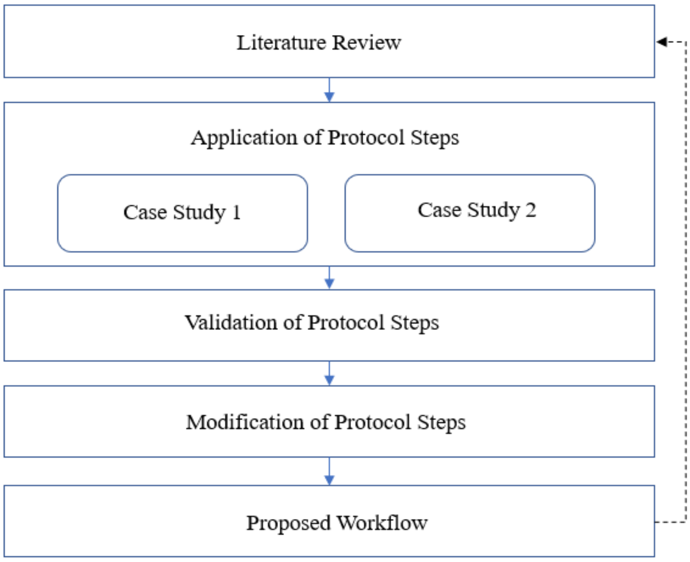


Fig.1: Research Methodology

| Theme | Protocol Steps | Duque et al., (2018) | Entrop & Vasenev (2017) | Rakha & Gorodetsky (2018) | Bown & Miller (2018) |
|---|---|---|---|---|---|
| **Selection** | Equipment Selection | X | | | X |
| | Site selection | X | | | |
| | | | | | |
| | Site risk assessment | X | | | |
| **Setup** | Drone pre-flight setup | X | | X | X |
| | Initial set-up phase | | X | | |
| | Construct flight path to connect all objects of research | | X | | |
| | Safe and secure flight area | | X | | |
| **Inspection** | Drone enabled inspection | X | | X | X |
| | Damage identification | X | | | |
| **Photos** | Use of photogrammetric software to recreate the building components | X | | | |
| | Photos and Videos storage | | X | | |
| | Photo formatting | | | X | X |
| **Summary Reporting** | Summary reporting | X | X | X | X |

Tab. 1: Identification of key steps and common themes as per literature review

Based off of the literature review, the above steps were used to conduct roof inspections at the Nauvoo and Independence sites. This was done as a preliminary test to practice following the compilation of protocols listed from existing literature. The DJI Mavic Pro (Fig. 2) was used for this study due to its easy portability, low cost and quick learning speed (72.5 learning hours). For an FM, this model has a reputation for providing appropriate benefit for a nominal investment. As a part of the learning, the operator/pilot was required to obtain the Federal Aviation Administration 107 licensing test for flying in the United States. The total cost of the drone, the accessory and the fees come to about $1,510.

Fig.2: Drone kit for roofing inspection

Case study 1 was performed at Nauvoo Visitors Centre located in Illinois with a roof area of 9,960 SF, shown in Figure 3. The building has a low-slope ballasted roof. The building was selected from the midwest region of the United States, as it experiences all four seasons of exposure and wear. The varying seasons also impact the roof penetrations and consisted of various mechanical units for heating and cooling the building. Case study 2, shown in Figure 4, was performed at Independence Visitor Center located in Missouri with a roof area of 10,010 SF. The building has a low-slope non-ballasted roof. The building was selected from the midwest region of United States, as it also experiences all four seasons, so as to identify any wear and tear on the roof.

Fig. 3: Case study 1 Nauvoo Visitor Center

Fig. 4: Case Study 2 Independence Visitor Center

Testing the literature review protocol consisted of following the general tasks shown on Table 1. This included site selection, equipment setup, general photo & video inspection and summarization of the data collected. Initially, the Nauvoo structure was drone-inspected in this manner alongside several other small structures in the local area. This process was carried out so that the authors could run an initial data validation while becoming cognisant of the process steps of the current studies.

The next step after the validation was the modification of the workflow steps to include a more complete perspective of the inspection intent. That is, to detail all viewable aspects of the roof as well as specific requests from its owners. It was observed that the full sequence workflow steps were not published and hence all the steps had to be combined and modified to fit the needs of the roofing drone inspections. The modified sequence of steps was added to the listed steps into a workflow system and was again tested at the two sites as needed to fulfil the research purpose. Both the buildings and a standardized full sequence workflow steps were proposed to carry out the drone roofing inspections. A detailed comparison of the existing and modified sequences is shown in the Discussion section of the paper on Table 2.

## 3. Findings

Through the investigational search of drone-inspection literature and the formation of a summary on Table 1, the authors were able to identify the past studies that have contributed to an inspection system for building roofs and other built structures. From this table, it was shown that, although there have been several portions of an inspection workflow proposed by previous authors, a full-length sequence had not been proposed and published. The lacking elements of the reviewed publications were outlined to be the following:

- Details of Actual Video/Photo sequences
- Owner-requested areas of focus within the structure
- Photo formatting and organizing for FM/owner review
- Testing of the full-scale process to demonstrate each sequence and how it fits into the full process

Additionally, the testing of such a full-length workflow was not possible to conduct because it did not exist. For this reason, a 5-step process was derived from the review along with a 4-part subset of steps for the photo and video flight data collection. These steps and subset items are listed below.

### 3.1. Inspection Field Notes

Similar to a surveying traverse, this step includes the compilation of a data record of items such as the date, weather conditions, general temperature, tools used and approximate time of day that the inspection was conducted. Additionally, names of the crew members involved with the inspection as well as the specific technical equipment (equipment selected) are recorded. Additionally, as a rule of safety, a site-risk assessment is also conducted to address any flight pattern hazards in the localized area. These hazards could be either on the ground or in the air surrounding the structure.

### 3.2. Equipment Checks

This is a brief inspection of the key flying equipment and an environmental assessment to assure proper safety to the pilot team and surrounding pedestrians. Equipment examination is carried out to assure that propellers are undamaged and free-spinning, battery life of the drone, remote controller and tablet screen are sufficient for the flight. Other components, such as spare parts and connections are verified to be safe and functional before take-off.

As the remote and drone are powered up, synced and lifted off of the ground, an in-flight check of the camera settings is made to assure that it is at the optimal settings for brightness, shutter speed focus according to the current sunlight amounts.

### 3.3. Drone Enabled Inspection: Picture Sets and Video Footage

The following steps outline the sequence of manually-piloted video and picture sequences that are recorded for observation and inspection. Of the four Picture Sets that are taken with a drone, one is with video footage and the other three are done with simple still shots.

a. Picture Set 1 - Short Video Isometric Swipe

The video footage consists of a short video taken of the whole structure as the drone moves sideways. This allows the inspector to see the isometric shape and roof composition in motion in order to grasp the overall exterior composition of the building. The “fly-around” video only lasts between 5-15 seconds.

b. Picture Set 2 - Top Views

This view is one taken from approximately 25-60 meters above the roof as the camera points directly downward at a 90-degree angle to the ground. Figure 5 illustrates this view from the two case study structures. It serves to give a single holistic shot of the structure and is followed up with several closer “regional” pictures of the various quadrants of the structure. The closer pictures allow for a more detailed summary of the surface of the roof.

Fig. 5: Examples of Picture Set 2 – Top Views

c. Picture Set 3 - Angular Views

This set of pictures takes various high definition “angular photos" of all major penetration points and parapet wall joints to the flat (or pitched) roof. This Picture Set is the most tedious of the data because it includes vent joints, chimneys, antennas, HVAC-related items, parapet walls, etc. Examples of this picture set are found on Figure-set 6, below. Photos are typically taken at about 5-20 feet from penetrations and from 2-4 sides. Occasionally there are environmental items, such as trees, power poles, and miscellaneous cables that make it difficult to get optimal views. However, the overlap of pictures over the areas should cover the necessary surfaces sufficiently.

Fig. 6: Examples of Picture Set 3 – Angular Views

d. Picture Set 4 - Special Requests & Problem Areas

This picture set is initially directed by the owner’s instructions. Special areas such as any roof damage, water ponding, window close ups, nests from animals or insects, mortar joint conditions or gutter conditions are typically requested areas. Figure 7 shows an example of an area where either damage or unfinished repairs have been undertaken. The pilot is also commissioned to document any unforeseen damaged or abnormal areas that are found during the flight inspection.

Fig. 7: Picture Set 4 – Problem area examples

### 3.4. Data management

Following the traverse of the pilot for inspection, the next step in the process is to compile all of the photos by structure, angle, footage and location. A hard copy of the electronic data (i.e.: thumb drive or hard drive) is given to the owner and the gps-stamped photos are also uploaded to a shared mapping service (such as Google My-Maps or Dropbox or another server-based storage source) so that the data is backed up on a cloud server and map.

### 3.5. Summary Reporting of Data

As a review of the pictures and video is conducted, a summarized report is created noting any areas that might be damaged, worn down or otherwise noteworthy for further review by the owner of the structure. This will allow for the owner of the structure to be given quick reference on what areas should be considered for further inspection, scheduled maintenance or emergency repairs.

## 4. Discussion

The literature review comparison of key steps and the proposed workflow steps is presented in this section as shown in Table 2. The identified thirteen (13) key steps were grouped in the five (5) common themes. These are common for both literature review steps and the proposed workflow. However, each major step has a different action subset as marked as a bullet point under each major step as shown below in Table 2. The subset was specifically modified and tested to be followed as a standardized full sequence workflow for carrying out roof inspections with drones.

Step 1 is derived from the literature review with the addition of recording crew members, weather conditions, location information etc. This helps to collect the data in a standard format for all roof inspections andhelps to mitigate the risk of excluding any data point due to human error. Step 2 is also based on the literature review information with the additional adjustments

| Steps | Literature review protocol steps | Proposed workflow |
|---|---|---|
| **1.** | • Equipment/site selection and site conditions<br>a. Equipment selection<br>b. Site selection<br>c. Site risk assessment | • Inspection field notes<br>a. Site selection and overview<br>b. Record data-time, weather, tools, crew<br>c. Safety risk assessment for flight pattern |
| **2.** | • Setup<br>a. Drone pre-flight<br>b. Initial set-up<br>c. Construct flight path<br>d. Safe and secure flight area | • Equipment checks and set up<br>a. Key flying components check<br>b. Environmental assessment (for proper safety of pilot team/pedestrians<br>c. Equipment examination<br>d. Camera settings |
| **3.** | • Inspection<br>a. Drone enabled inspection<br>b. Damage identification | • Drone enabled inspection<br>a. Picture set 1 (Short video)<br>b. Picture set 2 (Top view)<br>c. Picture set 3 (Angular view)<br>d. Picture set 4 (Special request and problem area |
| **4.** | • Photo formatting and organization<br>a. Use of photogrammetric software<br>b. Photos & video storage<br>c. Photo formatting | • Data management<br>a. All pictures compilation<br>b. Hard copy exchange and upload on cloud server |
| **5.** | • Summary reporting | • Summary reporting<br>a. Review<br>b. Special Notes |

Tab. 2: Comparison of Literature Review Key Steps and Proposed Workflow Steps

of the drone camera to be optimized for the lighting levels at the inspection site. Step 3 has the additional sequences with the four different "Picture Sets" that are outlined. These items were not found in any of the literature reviews and were derived from the inspection practice and formulation of the initial round of drone inspections. These sets were also developed through conversation and advice from the owners of the structures and consultations with roof inspectors. These sets included short video footage, overhead views of the full structure, angular views of each of the penetrations and parapet walls and any requested items as well as anomalies or damaged areas. Step 4 is taken to manage the recorded data into a common format for the review by the FM or the owner requesting the inspection as outlined in data management step.

The final summary, step 5, includes a review of the entire process with highlighted special notes of areas of focus. This report can be done on paper, presentation or via video conference. A finalized workflow diagram of this process is shown below in Figure 9.

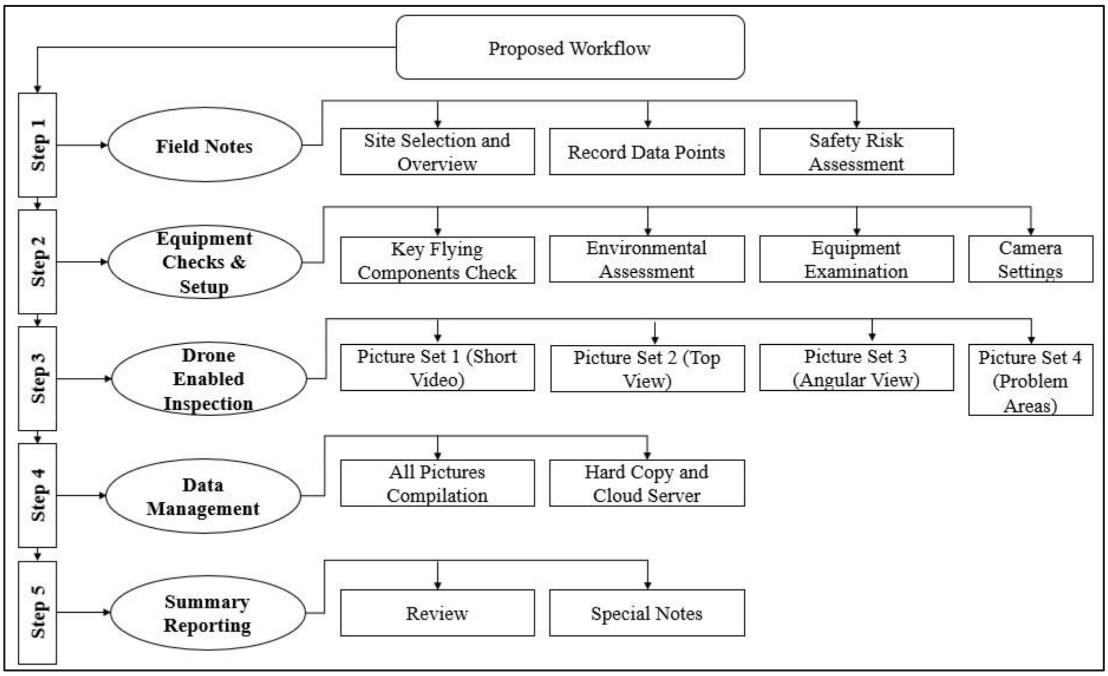


Fig. 9: Proposed 5-step workflow for drone roof inspections

## 5. Conclusion

In this study, the authors have documented and organized a set of protocols for drone roof inspections with low-slope roofs based on current research with Faculties related work. The literature review suggests that the use of drones is a beneficial alternative for low-slope roof inspections compared to traditional methods. After a thorough review of past inspection studies, it was concluded that there had been several versions of an inspection workflow proposed by previous authors. However, a full-length sequence had not been proposed and published. The lacking elements identified through this study that are added to the workflow are as follows: First, details of Actual Video/Photo sequences taken while in flight. Second, owner-requested areas of focus within the structure. Third, photo formatting and organizing for FM/owner review. Finally, it was necessary to conduct testing of the full-scale process to demonstrate each sequence as a part of the process as a whole.

From this protocol framework, the researchers worked to augment these protocols into a single-set workflow that included any logical missing steps and that could be applied to the drone inspection process. A proposed method of doing the inspection sequence was derived which attempts to cover all the known steps of roof inspections with drones. The 5-step “workflow” was developed from the literature review steps, which were then applied on both sites and were modified to specifically fit the drone roofing inspection workflow. The proposed sequence was tested and validated with two low-slope structures that are in the Midwestern area of the United States.

Although the technology and deregulation of drones has moved forward quickly in recent years, it is only through the testing and innovative practice of facilities managers that the true benefit of its use will be realized. Done use has proven to be a safer, more cost effective and quicker method for many types of structural inspections. However, this progress will only continue as more FM's are willing to invest the time, money and progressive management practices in using drone technology to help with their own properties and building envelopes.

Although this study is limited to low slope roofing systems, the sequence is considered general enough that it can be applied to various roof slope systems as well as other structures such as water towers, silos, cell phone antennae's and other structures. It is anticipated that this workflow can be applied to future inspections as a more standardized approach to roof and structure monitoring with drones.

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