Exploratory Study of Unmanned Aerial Vehicles for Building Inspections

A Roofing Inspection Case Study

by

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ABSTRACT

Unmanned Aerial Vehicles (UAVs) have become readily available for both the average consumer and professional due to decreases in price and increases in technological capabilities. This work ventured to explore the feasible use of UAV-technology in the area of roof analysis for facilities management purposes and contrast it to traditional techniques of inspection. An underlying goal of this work was two-fold. First, it was to calculate the upfront cost of investing in appropriate UAV equipment and training for a typical staff member to become proficient at doing such maintenance work in the practice of actual roof inspections on a sample set of roofs. Secondly, it was to compare the value of using this UAV method of investigation to traditional practices of inspecting roofs manually by personally viewing and walking roofs. The two methods for inspecting roofs were compared using various metrics, including time, cost, value, safety, and other relevant measurables. In addition to the study goals, this research was able to identify specific benefits and hazards for both methods of inspection through empirical trials. These points illustrate the study as Lessons Learned from the experience, which may be of interest to those Facilities Managers who are considering investing resources in UAV training and equipment for industrial purposes. Overall, this study helps to identify the utility of UAV technology in a well-established professional field in a way that has not been previously conducted in academia.

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CHAPTER 1

INTRODUCTION

UAV Prolific Use

Unmanned Aerial Vehicles (UAVs) have become practical tools used in many industries across the globe because of their explosive popularity to the general public (Forni & Van Der Meulen, 2017). In the Facilities Industry, UAVs have several applications to monitor and inspect different parts of a building and sites (Keane, 2013).

A thorough search of construction and facilities management documents concluded that there was little-to-no information published on roof inspections using UAVs. Furthermore, there was no work comparing the use of UAVs vs. a physical, traditional approach to roof inspections. This paper will help to answer the question: Which method of inspecting roofs will be the most practical to the Facility Manager, in terms of time and resources?

This paper compares two methods of performing a roof inspection: 1) Traditional/ conventional methods which require the inspector to physically climb to the roof to get a visual of the material conditions; and 2) State of the art methods where the inspector uses a UAV equipped with a high-definition camera.

When comparing, taken into account was: the amount of time it took to travel to the inspection site and to set up the equipment, obtain access to the roof, perform the actual inspection, the safety factors affecting the inspector, the retrieval, the processing, and the storage of the inspection data, and the maintenance of the equipment.

Data collected from inspecting roofs of several structures located under the jurisdiction of the current Facilities Manager (FM) in Nauvoo, IL. The structures consist of various small residential homes and two large commercial buildings.

The structures inspected in this case study in Nauvoo, IL, were historic homes that have been restored or reconstructed from the 1840s. Due to the historical value of these structures, inspections with UAVs would minimize the need for physical contact with unnatural objects and live loads. The avoidance of physical contact with historic structures is a great advantage to consider in preservation compared to the previous traditional inspection method performed by staff members (i.e., work boots walking on pitched cedar-shake shingle roofs).

Current Facilities included in the Research Approach

Nauvoo, Illinois.

Nauvoo Facilities Management (NFM) oversees the maintenance and new construction in the historic district in Nauvoo. The total number of homes managed by NFM is currently 146 structures: fifty-four historically restored or reconstructed buildings, twenty-four visitor and utility structures, two visitors' centers, ten public restrooms, an RV park, over a hundred apartment units for volunteer performers and tour guides, and over a dozen other miscellaneous structures.

Figure 1.

Artist Rendition of Historic Nauvoo

Grounds.

NFM also has several memorial gardens and planters throughout Nauvoo and Carthage. The largest garden in the world with statues specifically honoring women, an herb garden displaying the plants and herbs used during the 1840s, and several other planters and flowerpots to beautify the landscape. Two groves and over 5,000 documented trees, some being very exotic and rare, are contained within the area. Roughly 250 acres are mowed weekly, and several hundred acres of farm and forest land are also maintained.

Livestock.

A unique aspect of the management of Historic Nauvoo is caring for the livestock and continuously maintaining a program for their care. NFM owns twenty draft horses, two teams of oxen, and a new pair of bull calves. There are two barns, a breakroom, two hay tents, and several pastures to tend to the livestock. Three massive wagons and four large carriages provide means for the rides for the patrons with fifteen other historic wagons on display around the historic district between April to October.

Offices and Shops.

To maintain all that has been described, a large complex with many buildings was built. This complex includes office space, a large grounds building, four greenhouses, equipment storage, wash bay, an incinerator, break/conference room, gas station, sawmill, wood kiln, and several other shops used by the different departments. NFM has a fleet of vehicles, trailers, and several pieces of large equipment to assist with construction projects as well as routine maintenance.

Carthage, Illinois.

Thirty minutes southeast from Nauvoo is a four-acre historic site in Carthage, Illinois which contains a historic jail, a visitors' center, garden, and homes for seven missionaries.

Liberty, Missouri.

The sites located in Liberty, Missouri consist of two visitors' centers, one cemetery, two memorials, two homes, one office, one grounds shop and warehouse, and various fields and building lots.

Employees/Interns.

As of 2020, the staff consisted of twenty-two full-time employees, eighteen seasonal employees and seven interns from various colleges hired to work summer grounds, maintenance, and construction.

Volunteer Missionaries.

NFM has thirty-five to forty-five volunteer missionaries who assist full-time employees. The missionaries are usually retired professionals and are in their senior years. NFM also has seven young men who serve as volunteer missionaries.

The missionaries serve from six to twenty-four months. The missionaries are assigned to serve in Nauvoo by managers at Church headquarters in Salt Lake City, Utah. Once in Nauvoo, the missionaries are assigned to a department, based on their skill set. Each department has a full-time employee who manages the work and assigns work orders and projects to his team.

Structures.

There are seven flat roof structures, which are large commercial-type buildings where most of the visitors pass through. Of the 152 pitched structures, approximately one-third of them are authentic historic buildings.

Historic Structures.

Historic homes require a higher standard of maintenance because of their potential to be damaged. They have original features such as cedar shake roofs, parapet walls, historic brickwork, authentic wooden doors and windows, and brick chimneys. The fragile state of these features makes the inspection process difficult to perform while preserving the integrity of the feature.

Figure 2.

Typical Historic Nauvoo Home.

Additionally, the maintenance of 19th-century structures requires an added architectural and design aspect that is difficult to reproduce and maintain. Several high maintenance items were designed into the landscape to give visitors a more realistic and historical experience.

Utility Structures.

Roof inspections are also required for several utility-type buildings. These include horse barns, buildings adjacent to the barns for the horse program, loop buildings for storage of wagons and hay, other restored barns in the historic district, and sheds, restrooms, and other structures to help and assist visitors

Contemporary Structures.

Contemporary structures are large buildings that function as visitors' centers to the general public. Most of these buildings are flat roof structures with access points built into their design, therefore saving time because setting up a ladder is not required. Also, these buildings have four-foot parapet walls that create a safety barrier for the inspector and minimizes the possibility of falling off the roof, precluding the need for the inspector to use fall protection equipment.

Housing Structures.

Several single residential homes are occupied by volunteer missionaries having a pitched roof home with the same inspection process as the historic homes. The roofs on these homes are inspected but are secondary on the priority list because these homes are less visible to the patrons and are not visited by thousands on an annual basis.

Other homes have multiple units under one roof. Most are either tri-or quad-plexes. Sixty of these homes are in the historic district, being built in 2001, designed architecturally to blend with the historic nature of other homes in the area.

Overall, there is over 400,000 square feet of building space. Although this number may be smaller than a typical facilities manager in a commercial or public setting, these buildings are spread out over five locations in two states. Table 1 summarizes the structures by location and their respective square footage.

Table 1.

Summary of Structures Under Nauvoo Facilities Management Group

Location	Flat Structures	Pitched Structures	Approx. Square Footage	Other Structure Notes
Nauvoo, IL	5	141	378,600	Historical homes, restrooms, barns, visitors' centers, apartments, utility buildings
Far West, MO	0	1	1250 ft	Restroom utility structure
Liberty, MO	1	2	11,606	Cupola Domed roof at the center of the primary structure
Independence, MO	1	3	18,952	Visitors' Center, Shop, Office Complex
Carthage, IL	0	5	12975	Jail, Visitors' Center, Apartments
Total	**7**	**152**	**423,383**	NOTE: Some structures were omitted due to their smaller size (i.e., sheds, outhouses, utility buildings)

Technological and Public Progress in UAV Uses

Since the early part of the millennium, the use of unmanned aerial vehicles has grown dramatically, beginning with military and Special Forces missions (Sifton, 2012). Initially, such units were winged, unidirectional planes equipped with cameras, sensors, and even weapons (Rogers, 2017, May 12). However, in more recent years, the technology of such units has both improved while both the size and cost to produce such items have gone down (Meola, 2017, July 1). This has allowed for average enthusiasts to participate in their use as higher-level technologies such as high definition cameras, increased battery life, GPS tracking and flight programming, software development as well as payload capacity has increased. Although costs are still in the several-thousand dollars range, it has become more common to see UAVs being flown by private citizens in parks and other public areas. In the United States, a critical Congressional change occurred in 2015, allowing for more common use of UAVs in public places and by private citizens (Belton, 2015).

UAVs have opened opportunities in the built environment industry (man-made structures, features, and facilities) by allowing the facility managers to document inspections more quickly with in-depth and exceptional detail. Additionally, their usage has opened the considerations of being able to access locations that were never available by conventional and traditional means. Table 2 shows a list of brands used with their associated costs in this study.

Table 2.

Setup and Training Cost for Professional UAV Operator Capabilities

Item	Cost	Description	
DJI Mavic Pro Drone	$850	Standard DJI Model with stock gimbal and lens filter.	
UAV Storage and operation peripherals	$450	Hard-case storage containers, I-pad mini (used), extra propellers, 4-battery charging manifold, carrying pack.	
FAA 107 UAV Licensing Test	$150	Taken at participating airports	
Study Time for UAV Licensing Test	Approx. 12 Hrs.	FAA document and YouTube training videos used as study guides. 70% accuracy for passing grade.	
Inexpensive Practice Drone	$20-60	Drone with extra batteries and propeller protectors. The price range is between $20-60 for economic non-GPS models.	
Flying Practice Time	20-40 Hrs.	Recommended practicing at sporting events, weddings, hikes, etc. Outdoors, not indoors.	
Software Learning and Practice	20 Hrs.	DJI unit software, Drone deploy, Pix4d, Litchi, etc. Recommend using free software first, then free trial software period before deciding on software to purchase. Must learn specifics in Flight Planning programing.	
Totals: Costs Time	 $1,510 72.5 Hrs.	**$1,510 equipment + 1,812.5 Labor = $3,322.5 (72.5hrs x $25/hrs. employee rate)**	

In addition to the use of UAV’s, other areas and technological developments that have assisted in their industrial use are the following:

Global Position System (GPS) Linking.

A very distinct differentiation between drone types comes in the ability for them to link up with the global satellite grid system. This allows for the ability to track locations of flight, video recording, and pictures within a fraction of a foot. (McCormac, 2012).

Flight Planning.

Several third-party software packages can link up with the GPS linked drones to utilize flight planning, a process where a UAV can be pre-programmed to fly an automated flight pattern and capture video, pictures, or other data during flight. (“Powerful Drone,” n.d.)

2D & 3D mapping.

Very common with flight planning software provides the ability for the programs to link up or stitch together several smaller photos into a much larger mapped version of an area. This mapping process has blossomed into other methods for analyzing land area into 3D mapping, color isolation in agricultural settings, land surveying for engineering purposes, and even infrared mapping. (“Powerful Drone,” n.d.)

Agricultural Crop Monitoring.

The Farming Industry has begun to rely heavily on the automated scanning of crop growth and weed detection. This process enables both farmers and farm suppliers to track the progress of their products and detect potential problems before they arise more quickly. (“Powerful Drone,” n.d.)

Construction Inspections & Progress Data.

The construction industry has begun to use UAVs to document the exterior progress of projects as well as to detect potential problems on railways, roads, and roofs. Recent Trends have shown that various construction and engineering-related industries have also delved into the use of UAVs to help automate many of their practices (Banaszek, 2017).

Engineered Surveying Data Collection.

With the help of UAVs, software engineers have developed applications that can generate three-dimensional land maps aligning GPS grids and allowing for quick generation of land maps, distance, area, and volume measurements. (Walker, 2017.)

Commonalities in Industrial Progressive Use.

The reason for this increased use in many industries is a combination of price decreases, government allowance for the legal use of UAVs, and their ability to quickly obtain high definition perspectives from above and around land areas (Zhang J, et al., 2015).

Which UAV?

Most UAVs come from China, France, and the United States. The top professional brands of UAVs are DJI (Chinese), Parrot (French), Autel (United States), and Yuneec (Chinese). These manufacturers offer many choices, from the inexpensive for the novice pilot to the expensive for the professional pilot who uses the equipment daily (DJI, n.d.). Usually, a UAV can be purchased for under $1,000.00 on the low end, and the price increases from there, running into the thousands of dollars. (Fisher, 2018)

UAV Inspection Methodology

Video.

It was discovered there is a lack of zooming capabilities from video on UAVs, the detail needed to determine defects in the roofing material, the speed of the inspection, and evaluating the distance of the drone filming would have to be continuous.

Streaming.

Video footage creates large memory files which need to be uploaded somewhere accessible. This can be done both inside the drone itself or uploaded onto the internet depending on the capabilities of the drone. As the technology of video storage advances, video filming of roof inspections will be easier. Due to the same challenges of video filming, streaming a live feed would require another monitor, but more importantly, a constant feed of the internet at a set speed. In a small city in rural west-central Illinois, where the best internet speed available is subpar, quickly determining that video streaming was too slow.

Stitching.

Several applications have been created that stitch several small pictures together to produce one large image. As described in preliminary research, this option is not feasible for roof inspections because the detail needed is lost as the stitching fills the voids between pictures and creates a distorted image. (Bown, 2018). When testing the option of stitching in conjunction with the Bown study, the same conclusion was reached — coupled with the research presented in the above paragraphs and experimentation with a live feed, concluding that video recording, video streaming, and stitching were not sufficiently clear with the technology available to us. The decision was made to proceed with still pictures.

Roofing Maintenance & Inspections.

Maintenance and inspections of the roofing systems are completed semi-annually, usually during the Spring and Fall seasons. As a cost and time-saving measure, NFM staff combine the maintenance tasks (if needed) and the inspection of the roofs into the same visit, also preventing damage to the structure.

Maintenance includes the cleaning of rain gutters, removing debris from the rooftops, replacing damaged or missing, and replacing roof boots (pipe flashing). Once completing maintenance tasks, the staff member can then inspect the roof. It is important to note that when referring to roof inspections and the time for each review, maintenance activities were not included added to the time documented.

Performing Traditional Roof Inspections.

Most of the cost of inspecting roofs is labor and expertise. The time it takes to get the equipment ready and loaded, travel to the structure, equipment set up, then to perform the inspection adds up to a significant amount of time.

Equipment & Safety.

Any roof inspection presents a safety risk regardless of the heights and slope of the roof. Historically, 38% of construction fatalities result from falls ("U.S. Department of Labor," n.d.). Wearing fall protection during roofing projects is required, but when shorter inspections are needed on top of the structure to save time and effort, fall protection is often forgotten, or the inspector is negligent. This greatly increases the events of falls, injury, or death, depending on the structure height and condition. Any industry that deals with personnel off the ground is always looking for ways to save money and minimize risk.

When inspecting roofs or high portions of structures, much equipment is required. In Nauvoo, the inspection process occurs semi-annually, with other inspections more frequent when trees are located close to the structure. During these inspections, fall protection is required. Usually, a 45-foot man lift is used when the conditions are dry, but that is an expensive piece of equipment that most facility management groups do not have access to or are not willing or able to rent.

The next item that is needed for inspecting roof systems are ladders. NFM has several ladders of different lengths used for various applications and structures. Climbing ladders are required for accessing different locations that might be inaccessible with a man lift but as personnel climb ladders, the risk of falling increases.

Also needed is the vehicle for both inspections. Traditionally, a truck or vehicle is required to transport ladders or lift equipment.

Illustrated in Table 3 is the cost of the equipment used in traditional roof inspections.

Table 3.

Summary of Equipment Cost

Name of Equipment	**Life Span**	**Cost for NFM**	**Cost Per Use (6 Month Increments)**
Fall Harness & Roof system	5 years	$221	$21
Extension Ladder	20 years	$189	$10
Camera	5 years	$129	$12.90
Genie Man Lift (optional)	2-week rental	$800	$800
Roof Inspection Training	35 hrs./ $55 per hr.	$895/course	$89.50
Total Cost of Equipment/Training *Excludes the cost of the option of the man lift.	**$3359***		$783.40

Following an assessment of the NFM current method of roof inspections with existing equipment and manpower, the author then worked with the pilot on defining the requirements to have an in-house crew of employees become sufficiently trained and equipped with the necessary resources to conduct the inspections of their sites and structures. With this council, the following information was collected about such requirements showing equipment that was used in Figures 3 and 4.

Figure 3.

Mavic Pro UAV.

Figure 4.

Controls Setup to Pilot UAV.

CHAPTER 2

Proposed Method of Conducting Feasibility Study

UAV Inspection Development

In performing the first trial UAV flights and initial inspections, it became evident that a predetermined inspection protocol was needed, and a professional roofing inspector would need to be trained to use a UAV. The conclusion was to track the costs for outfitting an individual with UAV pilot training and licensing, and current knowledge in mapping software. The expenses were summarized to become a competent UAV pilot and associated software operator (U.S. Federal Aviation Fact Sheet, n.d.). After calculating the setup cost for a UAV, a breakdown of critical components of performing a traditional roof inspection was completed. The price was calculated for the equipment, training, and licensing in performing a traditional roof inspection. A comparison was then made between the costs of a UAV to the traditional method of inspecting roofs.

A second comparison that was most clear in concluding the most feasible method in roof inspections was to inspect the same roofs using both ways. The factors that were measured were:

1. The time it took to travel to the site
2. The time required to set up the equipment
3. The time needed to perform both inspections
4. The difference between the type of roof, sloped or flat
5. The square footage of the roof

The risk of being injured or fall off a roof is eliminated with the use of UAV's. Analysis organized in Table 4 tracks the time it takes for both methods of inspecting roofs based on its roof square footage size.

Table 4.

Protocol method and time estimates outlined by UAV Pilot and Facilities Manager for Inspections

Area	Measurable
Time Per Building to UAV-Inspect	15-20 Minutes per larger building. 10-15 Minutes for multiple buildings if adjacent to each other.
Setup and Takedown of UAV Equipment	10 Minutes
Compiling of pictures and final report per building.	30 Minutes
Items needed in UAV Inspection Kit	Single UAV, Backup UAV is helpful, 3+ Batteries Minimum, Car charger for continuous charging while inspecting.
Items Inspected (according to protocol)	Shingles, Gutters, Chimneys, Parapet Wall Joints, HVAC Units (connection areas), Cleanouts, Antennas/Dish attachments, Other Misc. Items.
Other Possible Items to Inspect (Extra costs and time outside of the standard protocol)	Window close-ups, Mortar Joints, Water Tanks, Signage, etc.

Traditional Roof Inspection Protocol

Sloped Roof.

The traditional method of inspecting a roof consists of assembling the required equipment, which includes a vehicle, extension ladders, fall protection equipment, camera, notepad (optional). The traditional roof inspection consists of traveling to site, and the inspector donning the proper fall protection. The ladder is removed from the vehicle, set up correctly and safely, and climbs the ladder. The inspector attaches a temporary roof anchor to the structure, connecting his lanyard to the anchor, moving the roof safely, protecting in case of a slip or fall. Several buildings in Nauvoo have permanent roof anchors installed that save time and minimizes the risk of having to install a temporary roof anchor.

A visual inspection of the roof is then performed. The inspector searches for damaged or missing shingles or shakes, soft spots in the roof structure, exposed nails, and loose mortar joints or flashing. The inspector also looks for torn or leaky pipe flashing at all possible penetration points and finishes the visible part of the inspection by viewing the ridge cap and gutters and downspouts. Pictures are taken, and notes are made, as necessary, to document the inspector's findings. The inspector then detaches his lanyard, removes the roof anchors (if needed), descends the ladder, and loads the ladder and other equipment onto the vehicle. This process is repeated for every roof inspection.

Figure 5.

Example of Roof Anchor.

Flat Roof.

For other facilities, this process could be very different based on the type of roof, size, pitch, and equipment. The large Visitors' Center in Nauvoo has a flat roof surrounded by a parapet wall. There is access to the roof from the 2nd floor. No fall protection or ladder is needed for such a roof. However, the sheer size of the roof may require more inspection time, primarily if problems are found.

Man Lifts.

The use of a man lift might be necessary to inspect the roofs depending adequately and accurately on the different characteristics of the roof. Because of its high cost to own and maintain, the lift is usually rented. However, if cost-justified, it may be purchased.

Man lifts are very efficient and safe in elevating personnel to areas above normal ground level, although several factors limit their use in Nauvoo, the main one being cost.

With the historic nature of Nauvoo, the safety of the visitors, and the possibility of the man lift leaving ruts in the grass are also concerns which may prevent the use of a man lift in certain situations.

In considering an inspection with the use of UAVs, a separate UAV licensed contractor was contacted, and few meetings were held where comparing the specifics of how a roof is currently inspected to the capabilities of what a drone could accomplish. The purpose of these meetings was to develop a standard system or protocol for viewing and recording the status of various kinds of roofs that could be followed by someone in the future.

A third-party roofing inspector was also consulted to add any other [possible] dimensions to how this could be approached (Gajjar, 2018).

From these meetings, a protocol list was developed that addressed the techniques for taking both pictures and videos while inspecting both pitched and flat roofs.

The contracting UAV pilot presented several preparatory actions that were needed for each inspection session. These steps, though familiar to the contractor, are necessary to list as a part of the protocol preparation, as shown in Table 4.

A crucial step when preparing to use a UAV is to ensure that the batteries have been fully charged and that several reserve batteries are available.

When operating the UAV, it was quickly understood that it was beneficial to be near the building being inspected, with the different angles and heights, it made sense to be close to the penetrations and parapet walls. The UAV is put together by installing the propellers, battery, and turning on the controls and monitor. Then, the controls and the UAV is linked and is then ready to take off for the inspection. The procedure is followed

as described previously under UAV Roof Inspection Protocol for each structure. The UAV is landed, disassembled, and put away, completing the protocol. If other structures are nearby, disassembling and repackaging might not be required.

These preparatory steps are essential to understand as a facility manager because they would be a part of the in-house employee training if this method of inspection was to be implemented

UAV Roof Inspection Protocol

The following sequence of video footage and picture recording was compiled as a result of the collaboration between the author, roof inspector, and UAV pilot and other published examples (Roca et al., 2013). This approach was developed to cover full view perspectives as well as penetrations and parapet walls on various types of structures. The sequence also includes the formatting (picture and video types) quality and level of definition to be presented to the facility manager.

Record Field Data of Inspection.

Date, Weather conditions, temperature, crew members, tools used, and time spent at a site. Additionally, record of any anomalies or unique conditions noted during the inspection. Lastly, reporting any areas that were not able to be recorded.

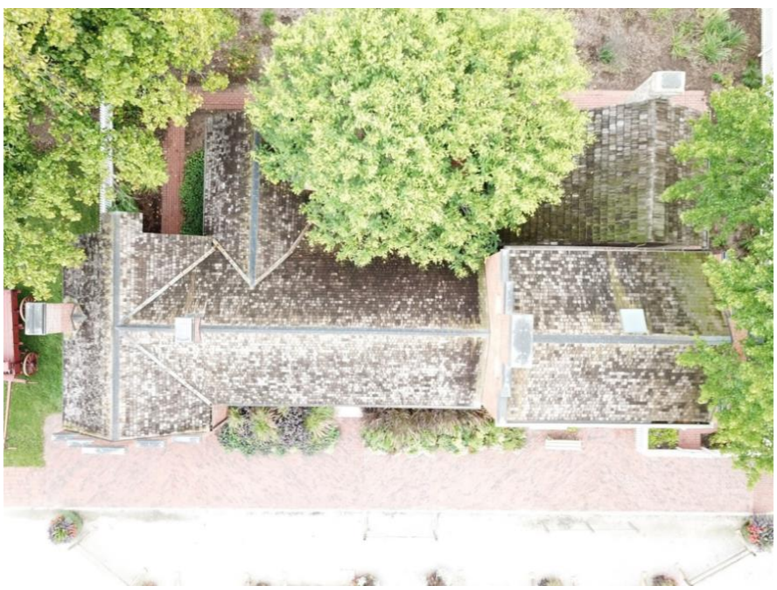
Setup check: High definition settings for pictures; medium definition settings for video footage. Verify Focus settings for close range (under 100 feet), Shutter speed, and Brightness maximum visibility avoiding “whiteout” or darkening effects on pictures.

Picture Set 1: Isometric view of building showing sides, roof, and architectural features. Include "fly around" video footage of structure to show a moving sample of structure.

Picture Set 2: Top full view (Typically between 20-80 feet above structure). Other Top views closer of corners, vital HVAC and other equipment, gutters, etc. (About 10-30 feet above structure)

Figure 6.

Top View of Historic Roof.

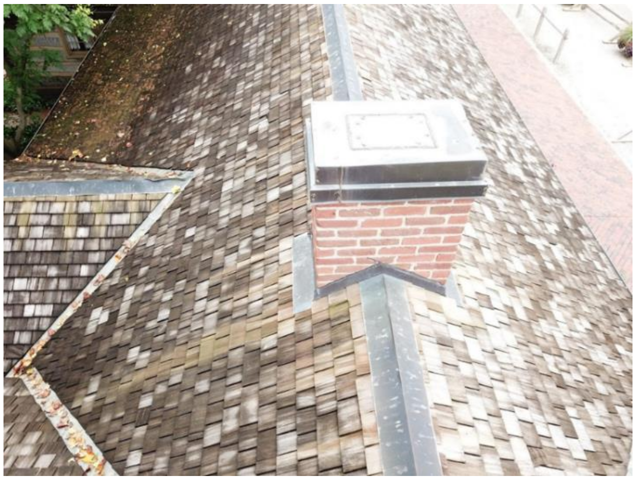


Picture Set 3:

45-degree angle shots of all major penetration points and parapet wall joints to the horizontal roof, vent joints, chimneys, antennae, HVAC-related items, etc. Shots typically were taken at about 5-20 feet from objects and from all four angles (if possible, depending on the structure and surrounding trees).

Figure 7.

45-degree Picture of a Roofline and Chimney.



Special Requests.

Pictures such as window close-ups, other useful images of distinctive features of the roof if they are deemed beneficial to review. (i.e., close views of rain gutters, hornets or birds' nests, other abnormalities).

Photo Formatting.

All photos placed are in a file folder that is dated, and original photo sizes are given to the owner. A cloud or external storage is used as a backup for the files.

Equipment Setup Check.

3 full charged batteries, and spare propellers

Structure Labeling.

Verify building numbers and locations before traveling. Ideal weather conditions are cloudy but still lots of light, to reduce shadowing in photo clarity. However, pictures can be taken in other circumstances with correct exposure, focus, and shutter settings.

Data Collection

As shown in Table 5, each of the eight structures that were inspected showed a shortened time-to-inspect by anywhere from 5-15 minutes except for one structure, the Browning Home & Gun Shop.

Table 5.

Time Duration Using the UAV to Inspect Each Sample Building

Area	**Measurable**
Time Per Building to UAV-Inspect	15-20 Minutes per larger building. 10-15 Minutes for multiple buildings if adjacent to each other.
Setup and Takedown of UAV Equipment	10 Minutes
Compiling of pictures and final report per building.	30 Minutes
Items needed in UAV Inspection Kit	Single UAV, Backup UAV is helpful, 3+ Batteries Minimum, Car charger for continuous charging while inspecting.
Items Inspected (according to protocol)	Shingles, Gutters, Chimneys, Parapet Wall Joints, HVAC Units (connection areas), Cleanouts, Antennas/Dish attachments, Other Misc. Items.
Other Possible Items to Inspect (Extra costs and time outside of the typical protocol)	Window close-ups, Mortar Joints, Water Tanks, Signage, etc.

CHAPTER 3

ANALYSIS

Cost Impact

Cost of Transition.

There is a cost of transition that is inherited when you are learning to pilot a UAV, gaining additional hours of piloting, and receiving licensing by the FAA. We have analyzed the cost associated with the training of using a UAV efficiently. There is a variable factor based on the individual's exposure to similar controls and technologies used in piloting a UAV. During data collection, we found that an individual can form the needed skills quickly to be able to follow the inspection protocol.

Cost of Inspections (Post Transition).

It has been discovered that over time, programming created for each structure could continue to save time, wherein the traditional roof inspection will ultimately remain the same both in time and risk. We continue to understand that fewer hours are being used as the route can be programmed with the UAV, and the pilot continues to improve their flying skills.

Resource Savings.

The savings of other resources is quite significant because there is no need for a vehicle that can haul an extension ladder, fall protection, tools to fasten the anchor to the roof. It should be noted that any repairs needed, cleaning, or tuckpointing, a vehicle plus attached equipment used for a traditional inspection is required, but if only for the roof inspection, none of that extra equipment is needed.

Risk Analysis.

The UAV inspections lessen the risk of serious injury or death to the inspector and liability to a company. This also ensures that damage isn't created from walking on the roof as the inspection is performed.

Time Savings.

The data in Table 6 illustrates that the UAV inspections take 39% less time to perform the roof inspection compared to that of a traditional roof inspection. UAV inspection eliminated the amount of set up time necessary for the traditional roof inspection, the donning of fall protection is crucial for the safety of the inspector and documenting the inspection. Taking pictures and writing notes creates several issues with time and safety, but this is not the case with the method of UAV inspections. A special vehicle is also not needed, in addition to transporting the necessary equipment, while that is almost nothing with UAVs.

Organization of Data Collected.

Another benefit of a UAV inspection is the amount of gathering data during the inspection and the amount of information it creates. Once complete, the set of photos is downloaded to a file with the building name, address, and date of the inspection. Analysis can continue for years after the inspections comparing the condition of the roof system from year to year.

Outdoor Complications.

Issues discovered while inspecting with a UAV was that it was almost impossible to provide meaningful information while experiencing heavy rain, high wind, or heavy snowfall. Another obvious concern is site conditions that might collide with the UAV while performing the inspection. Items like tree limbs, powerlines, and exterior lighting all present a potential hazard. If a collision did occur, the cost of repairs is expensive and sometimes involves replacement.

Battery Life.

The last challenge experienced was the battery life of the UAV is short. As time continues, improvements will be found and made, but it is always something needing attention.

Table 6.

Time Measurement Comparison Between UAV's and Traditional Inspections

Comparable Roofed Structure	**Relative Size & Roof Square Feet**	**Approximate Penetrations**	**UAV Minutes to inspect (Rounded by 5 min increments)**	**Traditional Minutes to inspect (Rounded by 5 min increments)**
Visitors' Center (Nauvoo)	21,580 Large	30	20 minutes	35 minutes
Family Living Center (Nauvoo)	7,060 Medium	3	15 minutes	20 minutes
Cultural Hall (Nauvoo)	1,900 Medium	6	10 minutes	20 minutes
John Taylor Home (Nauvoo)	2,086 Medium	5	10 minutes	15 minutes
Stoddard Tin Shop (Nauvoo)	871 Small	2	5 minutes	15 minutes
Browning Home & Gun Shop (Nauvoo)	2,090 Small	4	15 minutes	15 minutes
Post Office (Nauvoo)	522 Small	2	5 minutes	10 minutes
Printing Office (Nauvoo)	740 Small	3	5 minutes	10 minutes
Totals	**36,849 Sq Ft**	**55 penetrations**	**85 minutes**	**140 Minutes**
Percentages			**61%**	**100%**

CHAPTER 4

CONCLUSION

The purpose of this study was to compare UAVs for roofing inspections to the traditional methods used by a Facilities Management group. The two methods for inspecting roofs were analyzed comparing many aspects of the inspection, including time, cost, value, safety, and other relevant measurables.

The findings of the research indicate that the cost of the traditional inspection method is $1,566.80 per year. This includes the startup cost of UAV equipment, licensing, and sufficient training, estimated at $3,322.50. At first, the cost of the UAV is much higher, but overtime costs decrease based on improved skills, programming of set routes or inspections, and setup time in starting as well as the transition from one structure to the other. Once the initial costs to transition are completed, there is a notable saving in time and costs. In the research illustrated in this paper, it takes the UAV 39% less time to perform a better-documented roof inspection.

The Traditional Method of inspecting roofs with ladders and physically walking the roof has been the most effective technique to perform the task. Until now it has been the only way of inspecting. The cost to do so is relatively inexpensive, and once the basic equipment is purchased, its significant price is the labor of inspecting the roof. The inspector can take notes and pictures or video and keep a record of the findings. The safety of the inspector is a significant concern with the traditional inspections. Adverse weather conditions also increase the risk of injury for the inspector.

Overall, the traditional method of inspecting roofs has been a good option. However, with ever-improving technology, not perhaps the best anymore. With the risk of walking on the roof, climbing ladders, worrying about fall protection, and finally having to simultaneously write and take pictures while on a slick surface, or a pitched roof has the potential for harm. The risk factor is the most considerable difference between a physical inspection and using a UAV to inspect.

Other limitations are the time of the process it takes to inspect roofs. Findings show that on much larger commercial roofs, a physical inspection might be similar in time to a UAV inspection. But on smaller residential roofs, the UAV is more efficient with time. If the population of the structures is denser in the geographical locations, the UAV is more efficient and can save time.

The conclusion is that the use of UAVs is a better practice than the traditional physical roof inspection. Based on the lower risk of liability, the recorded data after the inspection, and the observance of increased efficiencies in flight patterns and pilot skillset as inspections continue, UAVs are the most feasible for the job. The technology of UAVs has quickly improved over the course of the last few years. As it continues, the time needed for physical inspections areas difficult to physically access will decrease and improve greatly.

Lessons Learned

UAV Roof Inspection.

As the research was performed, it became undeniable that there were both great things and disadvantages about the use of UAVs. There is always very little or no disturbance to the actual roof, which is very important to the authentic value of historic buildings. The data received from a UAV inspection far exceeds that of the traditional roof inspection with a few pictures and notes.

Another positive point of using a UAV to inspect roofs is the documentation of the individual roofs. It shows the entire roof, not just a picture of specific issues. The historical value of having that data could deem useful in years to come.

With continued use of UAVs in this area, the inspection process is expected to be shorter in time because understanding the different structures and the location of obstacles and obstructions. The pilot will also become more familiar with the flight patterns.

Still a Place for Traditional Roof Inspections.

A Traditional Roof Inspection is hard to substitute because of the qualified expertise from trained personnel. More focus can be spent in certain areas as needed or required. The use of other physical senses during the inspection is a benefit and will reveal things that could have otherwise been missed.

Risk is always involved when climbing ladders, walking on pitched roofs, falling, and even more dangerous when the roof is icy or snow-covered. The collection of data is usually minimal or non-existent.

Recommendations for Further Research.

- Cost analysis to fully train in-house staff to conduct inspections (investment of time and funds).

- Full facilities UAV roof inspection cost and time per square foot analysis on facility management resources.
- Analyzing data of UAV roof inspections over the course of several years to observe patterns and recurring issues.

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