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The Need for Commercialization of UAV for Building Façade Inspection

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Thirteen cities in USA are required to follow façade ordinance law for inspecting building façade. Traditionally the approaches to identify building façade defects are contact method with the help of monorail system, temporary suspended working platform and so forth. Visual inspections with contacted method suffer from several challenges and problems including low safety, low productivity, and low reliability. The results of visual inspection can be reliable when dealing with small structures with easily visible parts, but it is not easy for a surveyor to analyze high rise buildings or assess anomalies that are in deeper location without proper means of access and with unfavorable weather conditions. Visible inspection highly depends on the experience of the surveyor alone making the process subjective, human dependent, time consuming and having low accuracy in defect's measurement in certain situations. It is important to adopt a standard building façade inspection strategy which is fundamental throughout the life cycle analysis of the building. Unmanned Aerial Vehicle (UAV) coupled with good quality cameras to capture HD images and videos or infrared cameras and 3D laser scanners to identify damages and cracking in building facades is promising technology which should be commercialized to inspect building facades.

Keywords: UAV, building façade inspection, façade ordinance law

Introduction and Literature Review

Building façade refers to the face of the building or exterior of the building. Façade is a complex system to design, build and maintain, therefore there is a need of technological advancement in this department. Humidity is one of the main causes of façade anomalies but loads, stress, radiation, pollution, leakage, salts, molds, bacteria, insects, birds etc. may also significantly affect the façade's performance. Elements of building façade can fall off and cause threat to objects and people below if they are not maintained and inspected regularly. 51-year-old Nelson Salinas was found lying unconscious and unresponsive on a scaffold after suffering trauma from his head. 39-year-old Oumar Ba was walking down St. Johns Place in New York when debris and bricks fell from above on top of him. Erica Tishman died in New York city in late 2019 after being struck by a piece of falling façade from 105-year-old high rise in Manhattan. These are few among many façade fall related fatality that could have been avoided. The scope of façade inspection includes all the exterior surface including all the exterior features attached to the building, parts of building located on or near the exterior and externally mounted equipment (Guidelines on Periodic Façade Inspection, 2022) Inspection Practice includes visual inspection by a competent person. The

surfaced defects detected during inspection are documented by photos or sketches (Michael Y L. Chew et al., 2022). Building façade inspection involvers three major steps: planning, engineering analysis and execution and execution. Execution is the actual conduct of inspection (J. Mohammad, 2021). Execution of Inspection requires supervision by a licensed architect, structural engineer, or registered professional engineer. Building Façade Inspection can be Visual Inspection and Detailed (Visual and Hands-On Inspection). Most of the inspections are done visually by experienced professional with the help of visual aid equipment such as binoculars, cameras, flashlight, video camera with lens mounted at an extended flexible line for observing hard-to-reach areas, magnifying glass for hard-to-detect cracks, etc. Visual Inspection with contact method (Detailed Inspection) uses visual aid equipment and touching the surface by hands-on pushing, pulling, and probing to locate loose and degraded material and sounding to locate areas of delamination and future spalls (J Mohammad et al., 2022). Hands-on Inspection or contact inspection requires lot of time and manpower. One must ensure the skill of the façade inspectors along with their safety. They must ensure that the rope being used for surface access is properly hooked, the harness is in good condition, all the inspectors are provided with helmets and safety jackets, and they are wearing proper construction site-approved shoes. Therefore, the use of this methodology often meets with difficulties. It is hard to inspect the faces of building facade that are difficult to access, involves security risk for inspectors, poses safety risk for inspectors, and causes infeasibility for inspection of urgent nature due to high cost and unnecessary means involved in the inspection. (C Zhang et al., 2022). In the turbulent world of emerging technologies, it is very important to understand the relationship between user needs, existing solutions, and what new technology can bring to the table. This paper aims to understand if or not UAV is answer to the needs of modern complex façade inspections that requires higher accuracy and efficiency.

Façade Ordinance

Façade ordinance is a law passed by local authorities for periodic inspection of building facade to ensure public safety. The following table provides information on façade ordinance in 13 of cities in United States. Third column as written in the table (see table 1) provides information on Visual and hands on inspection requirement for each city. This column tries to highlight the potential market for usage of UAV for general visual and detailed visual inspection of building facades. Title 14 CFR Part 107 remote Pilot Small Unmanned Aircraft Systems Airman Certification is required for Drone usage.

Table 1: Façade Ordinance Requirements for different cities

City	Requirement for Inspection	Visual Inspection and Hands on Inspection
Boston, Massachusetts	Interval: every 5 years; Greater than 70’ in height or 35,000 cu ft	Buildings in category 79’-125’ tall requires only Visual Inspection.
Chicago, Illinois	Interval: every 4,8, or 12 depending on the category; Greater than 80’ in height or taller	Buildings for Short form program requires only Visual Inspection
Cincinnati, Ohio	Interval: every 8 or 12 years; Greater than 5 story height or more than 15 years old	Remote inspection allowed in place of hands-on inspection or to faces of façade that are more than 25’ from areas accessible to public

Cleveland, Ohio	Interval: every 5 years; Greater than 30 years old and 5 stories or 75' tall	Visual Inspection required from less than 6' along with hands-on inspection
Columbus, Ohio	Interval: every 5 years; Greater than 20 years old and located within 10' of a public right-of-way	Both Visual and Hands-on Inspection required
Detroit, Michigan	Interval: every 5years; Greater than 5 stories	Only Visual at distances greater than 6 ft and detailed (visual and hands-on) at distances less 6 ft inspection.
Milwaukee, Wisconsin	Interval: every 5 and 12 years based on building category; Greater than 5 or more stories and more than 15 years old	Visual remote examination for façade that cannot be examined through close visual examination
New York, New York	Interval: every 5 years; Greater than 6 or more stories, including basements	Approximately 25% of building façade requires hands on inspection while other 75% can be inspected visually
Philadelphia, Pennsylvania	Interval: every 5 years 6 or more stories in height or buildings with appurtenances more than 60' in height	Visual remote examination for façade that cannot be examined through range examination
Pittsburgh, Pennsylvania	Interval:1 year of adoption of code and successive inspection every fifth year of date of original inspection; all buildings except group R3	Visual remote examination for façade that cannot be examined through close-range examination
Saint Louis, Missouri	Interval: every 5 years; Greater than 6 stories	Visual remote examination for façade that cannot be examined through close-range examination
San Francisco, California	Interval: 10 years after initial inspection; Greater than 5 stories	Visual remote examination for façade that cannot be examined through close-range examination

All remote inspections can be done visually but not all visual inspections are remote. Visual inspections can be done remotely with advanced UAV technologies. For faces of façade that can be inspected remotely drone technology is a very good option. Facades that require only visual inspection UAVs can be used to access façade faces in challenging spots. For faces of façade that requires both visual and hands-on inspection drones can be utilized detect anomalies identified during the general inspection in difficult to reach parts of the façade.

Building Façade Defect Zone Classification

During the lifecycle of building operation defects and damages accumulate in the structure façade. Defects such as destruction of concrete protective layer, exposure of reinforcement, destruction of concrete of carnal slabs, absence of glazing on windows, destruction of wall panels, falling off plaster, molding, corrosion of fire ladders etc. occurs commonly if facades are not maintained properly. The building façade defects zone can be identified into five characteristic zones (T A Krahmalny et al., 2019). Defects can be in form of soaking, molding, corrosion, or distortion. These defects can lead to falling of concrete pieces from a height causing danger to the people and objects nearby.

Figure 1: Residential buildings in Brooklyn with building façade defects

Sidewalk Shed Erection

Sidewalk shed should be erected below the buildings which have been issued notice for façade inspection or buildings which have been deemed unsafe by the authority. Figure below (see fig 2) shows a five plus story tall building, in the 38th street, Queens, NY which was issued a notice for façade inspection. The sidewalk shed was constructed for safety of pedestrians and will remain until the building is deemed safe.

Figure 2: Different phases of sidewalk shed erection

Façade Inspection Report

Façade Inspection Report refers to the report prepared by licensed engineer, architect, or qualified personnel. It is prepared after the inspection has been completed. The report provides information on whether the building is safe or unsafe or if it needs repair. The report was acquired from a firm that was doing façade restoration work in a building with unsafe façade faces. Figure 3 (see below) is a snippet of façade inspection report out of 50 pages which were acquired from a façade inspecting firm. In façade inspection reports, defect is captured with help of camera, is highlighted, in the picture and the condition of the defect is explained. The inspection report ends with a table where pictures of defect with specific assigned numbers are tabulated, and recommendation type is assigned. The recommendation type can be to remove, to replace or to repair. Every façade inspector is required to use ASTM E 2270 Standard Practice for Periodic Inspection of Building Facades. Façade defects should be highlighted in the picture when report is prepared, and condition of the defect should be made clear as per the façade ordinance of the city.

Figure 3: Pictures of building façade defects as shown in pages of façade inspection report

Research Goals and Methodology

The goal of this study is to prepare survey data on the need for the Commercialization of UAVs for Building Façade Inspection. It aims to establish why building façade inspection is important and present interview results of professionals who have experience with Building Façade Inspection procedures, their opinions, and feedback on usage of UAV for building façade inspection.

Method of this study has three phases: content generation, data collection and assessment & evaluation. Phase 1 (content generation) aims to create set of questionnaires to interview professionals who have experience with Building Façade Inspection. The questionnaire will be curated to show the current trend in building façade inspection, their challenges and gauge if UAV is the answer to those challenges. For this research three questions were prepared. Phase 2 (data collection) aims to collect data by means of interviews and/or google forms prepared with the set of questionnaires. Phase 3 (assessment & evaluation) aims to conclude the data from phase 2.

Results and Discussion

178 people were interviewed for the purpose for this research. 95% of the responses were through the interview process and 5% were through the responses recorded through the distribution of google forms. Most data were collected through interviews because interviews provided access to ask follow-up questions and to go in-depth regarding the subject. The sources of the interviewee have been described below:

1) NYC DOB build safe, live safe Networking Event

Around 12 people were interviewed during this event which happened on July 29th, 2022.

2) Chicago Build Expo 2022

18 people were interviewed during the two-day expo from Oct 13 – Oct 14, 2022.

3) LinkedIn

6 responses were collected from the google link distributed to building façade inspectors in LinkedIn

4) Cold Calling and Email

142 interviews were conducted via cold calling and emailing AEC (Architectural, Engineering and Consulting) firms, building owners and engineers who have experiences with building façade inspection. Among which 105 were conducted during the process of National Science Foundation Innovation Corps (NSF I Corps) cohort program in costumer discovery phase.

The interviewee comprised building architects, engineers, project managers, designers, estimators, building owners, licensed building inspectors, facility managers, and others. Others include superintendents, licensed safety personnel, restoration workers, and people who have been in construction for one or more years. Most of the interviewees were employees of an architectural firm, a contracting firm, or an engineering firm, or were working in the building inspection department or local authorities. Three questions asked during the interviews were:

• "What are the challenges faced during building façade inspection with the conventional procedure?"

• "Do you think UAVs can address the challenges faced during façade inspection? If yes, could you name some of the challenges that could be addressed by the usage of UAVs?"

• "Do you feel comfortable in adopting UAVs for façade defect detection?"

For the first two questions, only service providers (104) were interviewed as it involves one to have experience in conducting façade defect detection to answer the question. For the last question, both service providers (104) and clients who receive building façade inspection services (74) were interviewed (178).

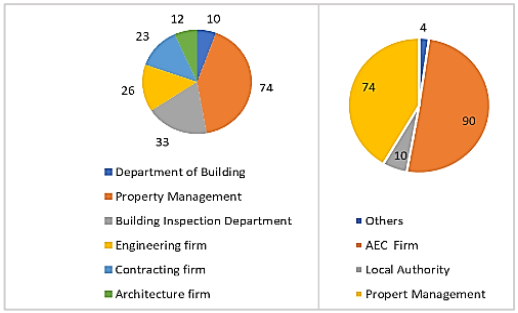

Figure 4: Demographic of Interviewee

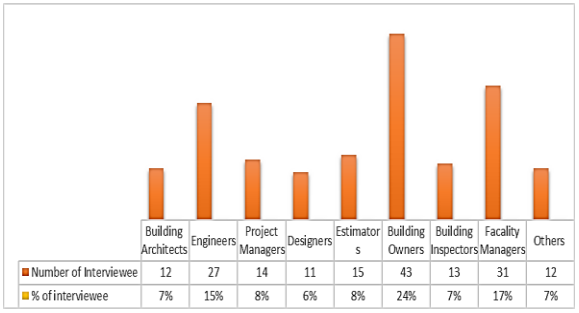

Figure 5: Interviewee Designation

Interview Results on Challenges Faced during Building Inspection

For the first part of this interview, the interviewees (104 service providers) were asked to name some challenges faced while doing building façade inspection with conventional procedure. Interviewees were asked to name top five challenges faced with conventional procedure. List of challenges and number of interviewees who named these challenges as their top five has been tabulated below.

Table 2: List of challenges and the number of interviewees who named them.

Challenges with conventional procedure	**% Of Interviewee who named them**
Time Consuming	96%
Unable to inspect blind Spots of Building façade	100%
Danger of fall while in a monorail system or hanging through rope	86.5%
Challenging to inspect facade complex structure	100%
Errors in defect detection	85%
Unable to cover 100% of façade area manually	100%
Errors in report generation	96%
Lack of awareness regarding building façade maintenance	92%

Top three challenges which were named the most by interviewees is described below along with quoted sentences. Quoted sentences written below are some parts of the sentences spoken during the interview conversation which might not have the exact same wordings but aims to express the same meaning. Most of the data collected were from interviews done via audio or video call.

1) Manual Inspection is not able to cover 100% of the façade area of the building

As quoted from one of the service providers of facade inspection "It is not possible to cover 100% of the façade area especially if the building is in highly populated area and there is a narrow gap. Even in such cases we try to inspect those faces by employing advanced assess equipment but even then, sometimes we are not able to cover 100% of the area". Many agree that even though manual inspection is most widely used technique automated inspection if done correctly will hold same if not higher accuracy. "UAV should be used and must be used to aid building facade inspection especially of high-rise structures" says one of the engineers from EDG Firm in New York.

2) Danger of life while accessing height of building façade for inspection.

It is very challenging to inspect façade with complex structure without advance technological support. Façade access equipment that are used for manual inspection to access height will always pose danger to life. Some of the building façade access equipment are: Bosun's chair, Building Maintenance Unit (BMU), Davit etc. "There is always danger to fall" says one of the interviewees. "There have been cases where scaffolding, trench and access equipment has collapsed. So, there is always a risk when manual inspection is opted" says project manager who works in Technico Construction, New York.

3) Unable to detect blind spots of building façade

Blind spots of a building structure often remain undetected while manual inspection if advanced technologies are not used. Many interviewees agree that there is lack of awareness among people regarding the importance of building façade inspection. According to the service providers "Many clients when they come with the request to get their building inspected would only get the building inspected if law requires them to or if their building is deemed inhabitable by local authority of the city. There are very few building owners who come for building inspection services for their personal assurance. Therefore, it is important that the building owners must be made aware of the dangers to risk of life posed by damaged building facades". This is a quoted interview provided by one of the service providers in New York City.

Interview Results on Usage of UAV For Building Façade Defect Detection

The data shows results of 104 interviewees who were service providers. The question asked was "Do you think UAV can address the challenges faced during façade inspection? If yes, could you name some of the challenges that you believe UAV can address?". All the interviewees agreed that UAV can be used to address the challenges in building façade inspection. 100% the interviewees who were service providers agree that UAV can be used to:

- Investigate blind spots in the building façade area
- Cover more façade area for inspection for increased accuracy
- Inspect building façade remotely
- Minimizing the risk of fall when hanging through rope system for inspection
- Cut cost in equipment's needed for laborious manual inspection
- Aid Human inspection for more accuracy

Interview Results for UAV adoption choices for Building façade Detection

Four options were given to interviewees as shown in the table (see table 3). They were asked to choose one of four. The interview results showed that most of the interviewees are comfortable adopting UAV to aid human inspection rather than using it remotely for fully automated inspection. This result was very understandable because using UAV remotely is still a very new technology. 27 of the interviewees who were all service providers said that they are comfortable in adopting fully automated remote inspection if law allows. 41 interviewees who were mix of clients and service providers were comfortable in using UAV only for inaccessible locations. 102 interviewees among which 92 were service providers were comfortable in adopting UAV to aid human inspection. 8 interviewees who were facility managers were comfortable with the existing technologies because they were unsure if the new technology bears same accuracy as the conventional one. 100% of the interviewee who were service providers were open to adopting UAV for building façade inspection if law would allow. 8 interviewees were not comfortable in adopting UAV for façade inspection and they were all clients. The clients who were not comfortable said so because they feel manual inspections bears more accuracy.

Table 3: Data for different UAV techniques interviewees are comfortable adopting

UAV adoption choices		**Number of Interviewee who named them**
1	Usage of UAV for fully automated remote inspection	27
2	Usage of UAV for inaccessible location	41
3	Usage of UAV to aid manual inspection for increased accuracy and efficiency	102
4	Usage of Conventional Manual inspection techniques without UAV	8
	Total	178

Conclusions and Future Research

Interviewees agree that having UAV for façade inspection: reduced the cost of building inspections, shortened the duration of building inspections, and provided more area coverage than manual inspection in a shorter time. The data shows that the building industry is very much willing to utilize UAVs. The results show that there is an inability to cover 100% of the façade area manually, unable to detect blind spots, and the risk of falls are the top three challenges of conventional inspection. Interviewees agree that these challenges can be addressed if UAVs are used. The other challenge is the safety of building inspectors who must hang via monorail along the façade surface for inspection which includes a range of hazards such as falling off, exposure to bacterial hazards, fungal hazards, or even physical attack by violent occupants. From the survey results gathered from this research, it is found that about 15% of the interviewee were comfortable with the idea of adopting UAVs to replace human inspection. About 23% were comfortable with using UAVs for inaccessible locations and about 57% were comfortable with adopting UAVs to aid human inspection. There were around 4% of the interviewees were not comfortable with adopting UAV for the façade inspection because they did not have much knowledge about it.
It was identified that the danger of collision of UAVs with pedestrian and nearby buildings will be reduced significantly if drone-based inspection were to have an automated optimized path. Optimized UAV path that can detect obstacle should be studied for future research.

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