

Eye in the Sky—Mitigating Facade Access Risks through UAVs' Aerial Imagery

By Kimani Augustine, PE, and Michael Cobb



Figure 1. Swing stage collapse in Houston, TX.

Photo courtesy of Houston Fire Department

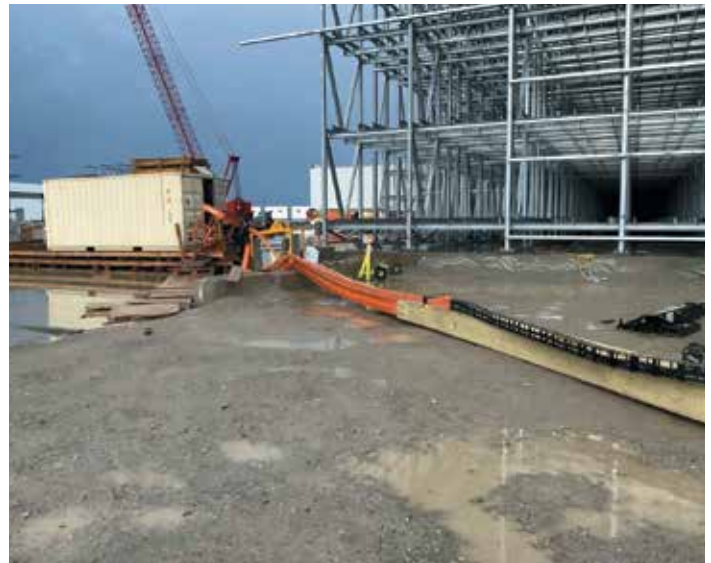


Figure 2. Aerial lift overturning collapse.

Photo courtesy of Lebanon Fire Department

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FACADE ACCESS AND maintenance are often integral aspects of commercial building operations. Utilized by a variety of services for tasks such as cleaning, repair, and glass replacement, these access systems are critical to the long-term health and performance of the building. However, these access methods are not always fully considered when developing the initial design of buildings and can result in challenging access scenarios that lead to undue risk of injury and death. While new buildings can begin to incorporate further coordination of access systems into their design, existing buildings still require service, and every hour that workers are in an elevated condition can lead to additional fall-hazard risks. To help mitigate these risks, drones and uncrewed aerial vehicles (UAVs) are being used to survey the built environment, particularly within the scope of reviewing and documenting conditions on existing facades and other enclosure systems.

TRADITIONAL ACCESS METHODS AND RISKS

Methods of access for humans have become varied and evolved to accommodate many unique scenarios; however, two methodologies, suspended scaffolding and aerial lifts, constitute the majority of access methods for temporary access and repair work. Suspended scaffolding is defined by OSHA 1926 Subpart L as “one or more platforms suspended by ropes or other non-rigid means from an overhead structure(s)”¹ and

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includes swing stages, boatswain's chairs, and hung platforms. While suspended scaffolding is a proven and adaptable method of access, this approach still involves strict spatial requirements and other associated risks (Fig. 1). Firstly, according to OSHA general industry standards 1910.140(c)(13)², the roofs must either have the capability for the stage to be anchored to davit arms designed to resist 5 kips (22 kN) of load at the point where the staging steel wires are attached or have enough space and access to install outrigger beams with enough length to ensure that the lever arm can be balanced with counterweights. Secondary fall protection must also be provided by using tieback anchors for not only the staging equipment but also individualized ropes and tiebacks for each worker on the stage. It is also important to note that while suspended scaffolding, if properly operated by trained personnel, can be a relatively safe means of vertical access, there are also inherent potential hazards. One fatality was reported to OSHA in 2021 due to an accident on suspended scaffolding, and three severe-injury reports were noted.³

Aerial lifts are defined separately as "any vehicle-mounted device used to elevate personnel."⁴ These lifts are often economically beneficial in comparison to the cost of temporary suspended scaffold systems. These lifts are typically driven from the basket and then extend out. However, there are some direct limitations associated with these lifts.

Firstly, firm, unobstructed, vehicle-ready driving surfaces and open aerial space are needed to deploy the lifts. The larger lifts can

be up to 10 ft (3 m) wide, and the wheelbase extends further when the lift is fully deployed. Secondly, the largest aerial lift available reaches a maximum outreach of 295 ft (90 m). Therefore, any work that extends beyond the 295 ft span must be performed and reviewed by another access method. Both of these limitations come with significant risks as well; overturning of the lifts due to the wheelbase not being set on stable ground is a known hazard associated with aerial lifts (Fig. 2). Secondly, when the lift is extended, it becomes susceptible to contact with power lines. While OSHA guidelines dictate a minimum working distance of 10 ft from power lines in aerial lifts,⁵ reported accidents do occur. In 2021, 33 aerial lift accidents were reported to OSHA; of those reports, 23 were fatal.⁶

UAV DATA CAPTURE

UAVs can often provide high-resolution imagery of building facades and enclosures without requiring human access. UAV data can be captured in a variety of methods; those most common to the built environment are visual spectrum photography, three-dimensional (3-D) photogrammetry, videography, and infrared thermographic imagery. Photographic capture is taken primarily with two methods: individualized photographs and photogrammetric scanning. Individual photos are commonly used to identify individual areas of interest and deterioration that can then be collaborated with field-documented site notes.

3-D photogrammetry, alternatively, utilizes a sequenced, overlapping series of photos to systematically document an area or volume. By

overlapping photographs containing identifiable, unique features, photogrammetry enables the recreation of a 3-D model utilizing these unique points to tie the photographs together. Photogrammetry is often utilized in conjunction with light detection and ranging (LIDAR) to create accurate scale models of buildings while also capturing detailed photographic data of the building.

While reduced risk due to the ability to utilize UAVs to perform visual reviews of enclosure systems is valuable, there are also significant effort and time optimizations associated with performing visual assessments with UAVs. Firstly, from a visual review perspective, staging is not required to be installed and moved for each drop, allowing for quicker mobilization between differing sections of the facade. Secondly, since photos in photogrammetry are taken sequentially while the UAV is flying, entire faces of enclosures can be documented in hours rather than days. While this does not incorporate postprocessing review of the photographs or development of a photogrammetric model, typical review of photographs for a full photogrammetric building 3-D model can require up to approximately 40 person-hours (Fig. 3). However, this model, once created, can serve as a baseline for future monitoring and facade maintenance planning of the facility.

EXAMPLE LOCATIONS RESTRICTING FACADE ACCESS

UAV reviews of existing enclosures become even more advantageous when traditional access methods are challenging and expensive.

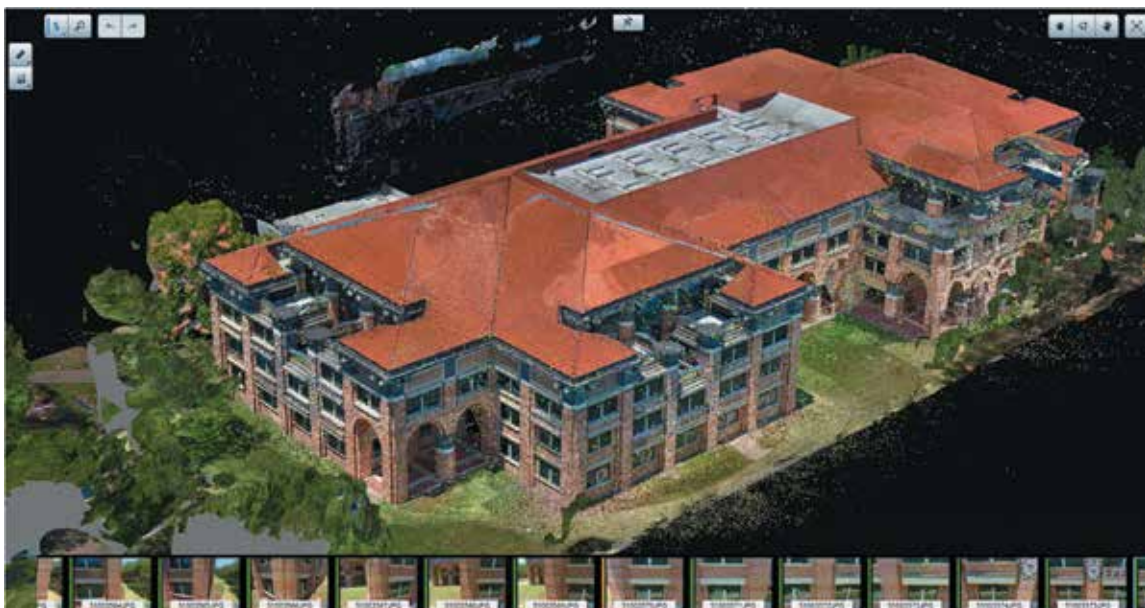


Figure 3. Photogrammetry model of a four-story institutional building from unmanned aerial vehicle imagery.



Figure 4. Aerial imagery of the exterior of a masonry-clad parapet.

Challenging access locations are common in tall buildings where facade access methods were not incorporated into the initial design, resulting in challenging staging scenarios, large-scale structures, complex architecture and geometries, and work sites near utilities and electrical hazards.

Since the first skyscraper, the Home Insurance Building (c. 1885, Chicago, IL), tall buildings often required facade maintenance from ownership; however, as safety regulations have changed and OSHA regulations for work at height were introduced in the 1980s, new access methods and technologies have replaced the less safe methods for which buildings were originally designed. Existing high-rise buildings therefore often do not have sufficient facade access system coverage, which then requires costly staging mobilizations or, in some cases, results in contractors resorting to potentially unsafe or nonengineered modifications for facade access. An example case study is a 28-story building constructed during the 1960s where masonry distress had been reported on the approximately 28-ft- (8.5-m-) tall brick-clad parapet (**Fig. 4**). The building was not originally constructed with engineered facade access systems, and the height of the parapet presented significant staging restrictions for review of the brick distress conditions. Due to these challenges, the staging costs alone for rigging a suspended scaffold to survey the parapet at the full perimeter of the building were prohibitively expensive. UAV surveys were utilized to collect visual spectrum photography imagery to document distress conditions at the exterior brick-clad parapet; the photos were then postprocessed to develop a distress map and identify specific drop zones that required arm's-length review from suspended scaffolding (**Fig. 5**). This approach saved the owner 90% of the initial staging cost estimate, which was then utilized to enact the necessary repairs to the brick parapet. While UAV surveys do not replace arm's-length and tactile inspections, these surveys



Figure 5. Arm's-length review of noted parapet distress.



Figure 6. High-rise building with elevated atrium and glass sunshades.

allow for more precise and targeted reviews of the condition of the building's enclosure systems, thereby reducing the risk profile to owners and engineers.

Besides locations of limited access, the size of structures can also provide challenges to traditional access methods. A case study indicating these limitations was conducted at a high-rise building. The 55-story tower had experienced spalling of the precast-concrete panels. The building owner retained an engineering firm to determine the cause and extent of spalling occurring on the tower. While the tower itself had a permanent on-site

building maintenance unit (BMU) and therefore had no significant monetary costs associated with staging, each drop for visual review of the tower was expected to take six to eight hours, with 39 individual drops. For safety purposes and per the BMU's engineered written procedures, a second engineer was required on the roof to coordinate with building security and implement emergency descent, if needed. In total, the facade assessment effort would have taken a minimum of 468 person-hours for data collection, with upwards of 200 person-hours suspended inside the basket of a BMU. By utilizing UAV data collection, images of the



Figure 7. Nonstandard grid shell at Het Scheepvaart Museum in Amsterdam, The Netherlands.



Figure 8. Medieval bridge tower over a river with limited roof access, in Prague, Czech Republic.

entire facade were collected in three days, and a model of the building to document distress in the precast facade was developed. Based on the UAV imagery data, follow-up arm's-length site visits were performed at the three drop zones determined to exhibit the most significant extent of concrete spalling distress. A comparative analysis of the arm's-length and UAV survey data collection was then performed to develop a reasonable extrapolation of distress quantities across the entire facade of the building. Subsequent construction observations during implementation of repairs by a qualified restoration contractor determined that the distress data quantification, utilizing this hybrid UAV/arm's-length site evaluation approach, was within approximately 10% of the field-completed repairs, which saved the owner in engineering and contractor labor during the investigatory phase. This hybrid assessment methodology also substantially reduced the field time during which individuals were suspended from the building in the BMU, which inherently decreased the fall-

hazard risk profile and provided an overall safer approach to the project.

Another area where UAV imagery provides a cost and safety advantage to owners and maintenance teams is in buildings with complex geometry. Buildings with elevated atria and curved surfaces provide challenges to traditional access methods designed to be deployed from roofs and ascend vertically or to be accessed from the ground level. For more contemporary architecture, UAV imagery thrives. However, as architecture becomes less ortholinear, traditional means of two-dimensional field notes become increasingly challenging to capture individual elevations and the use of 3-D models for field documentation becomes critical. Meanwhile, these complex shapes are often challenging or not viable to access using suspended scaffolds or aerial lifts and are often uneconomical to access via traditional fixed scaffolds. These risks can come from elevated atria with protruding architectural features (Fig. 6), multiple atria with limited roof access to these locations,

cantilevered enclosures, or large spanning glass roofs with irregular framing (Fig. 7). Historic buildings also pose unique opportunities for the utilization of UAV imagery. Historic buildings often have limited roof access and roof capacity, tall cupolas or spires, or large cornices often with limited access to the facade around the buildings (Fig. 8).

As previously discussed, 23 fatalities occurred on aerial lifts in 2021 in the United States, as reported by OSHA. The majority of these deaths were due to electrocution due to collision with power lines. Work on existing facades and building enclosures inherently requires working around existing infrastructure and the dangers associated with the transmission of high-voltage electricity. By incorporating UAVs into review at locations where power lines and transmission lines are near facade elements, the risk profile of electrocution is substantially diminished from the list of potential hazards during site investigations.

Summarily, data capture using aerial imagery reduces site evaluation time, reduces maintenance and repair costs for property owners and managers, provides more accurate and functional site documentation through 3-D photogrammetric models, and reduces exposure to site safety hazards.

WORKFLOW OPTIMIZATION

While UAV imagery plays a role in the manual capture of the existing conditions of building enclosure systems, the workflow around UAV imagery in the built environment is rapidly evolving. As systems for photogrammetric capture mature, the manual process of developing models and identifying distresses continues to become more automated.

Automated UAV flights have become common in the enterprise environment. By utilizing either GPS or off-the-shelf black-box software based on vision, UAVs can fly repeatable missions of the same capture points. The repeatable flights allow for comparative photographic analysis and documenting the progression of facade distress issues.

By utilizing a combination of photogrammetry and LIDAR, 3-D models can be updated through regular flights to provide a constantly evolving model of the building. This "living model" can be utilized for periodic monitoring and capital asset maintenance programming of enclosure systems. Living digital twin models can provide owners with the necessary information to proactively allocate budgets for future maintenance projects and identify potential issues that require more immediate attention. These models can

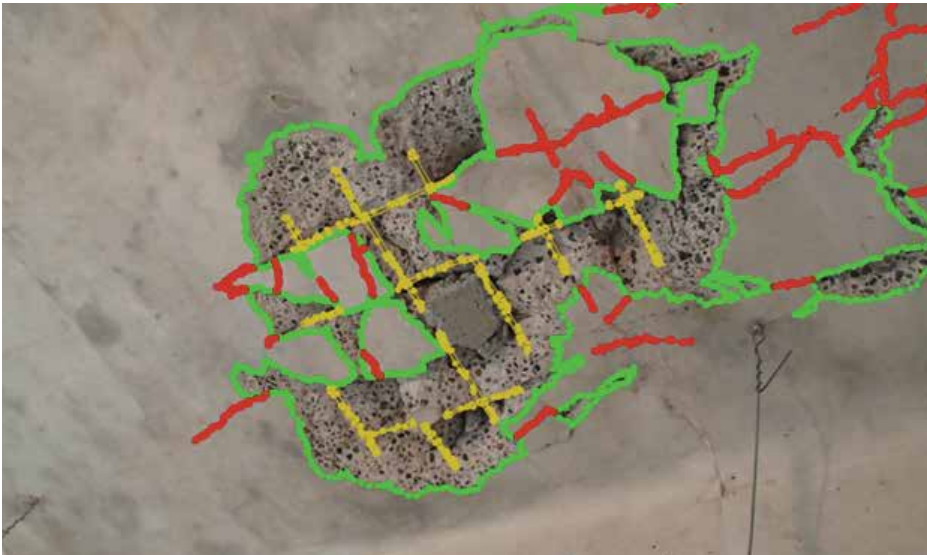



Figure 9. Automatic edge detection of spalling, cracking, and exposed reinforcement in concrete.

also allow owners to view the progression of deterioration by comparing the condition of specific areas between updates. Living digital twin models can also facilitate direct communication to contractors of the locations and distresses identified for repair, as the distress can be tagged directly on the model that has been created from existing conditions rather than on idealized and sometimes out-of-date construction drawings.

The latest optimization in the workflow process is the use of machine learning to detect distress in building materials, such as reinforced concrete, using photos. Vision-based automated crack-detection software for using deep-learning algorithms has recently moved from the academic to the enterprise space. Commercial off-the-shelf software is openly available for use, while engineering services companies have begun to offer bespoke systems focused on concrete crack and spall detection (Fig. 9).⁷ With an accuracy of greater than 70%, automated crack detection can reduce the time for the visual review of cracks by up to 85%.⁸

CONCLUSION

By combining workflow optimizations, UAV imaging, and traditional access methods, engineers can document, evaluate, and present data to asset owners in days rather than months, allowing engineers to spend more time focusing on building performance and root cause analysis instead of active site documentation. This increased efficiency is also coupled with increased safety. As drones are flown to identify visually evident distress and used in tandem with arm's-length visual reviews, workers spend less time at heights and less time on suspended scaffolds or aerial lifts, and therefore less time in high-risk environments. In

turn, building owners, property managers, and engineers are able to reduce their costs and risks associated with facade maintenance and capital asset maintenance planning while increasing the safety of personnel involved in accessing building facades. 

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ABOUT THE AUTHORS



KIMANI AUGUSTINE, PE

Kimani Augustine, PE, is a senior project manager and principal in Walter P Moore's Diagnostics Group. He has been in the industry since 2004 and has experience in diversified aspects of enclosure diagnostics, including conducting field visits and

assessments of existing structures requiring retrofit or renovation. Augustine has led efforts on many building enclosure and parking restoration projects. He has taken the lead on several significant facade access and roof renovations, including project scopes that involve the assessment and repair of multiple roofing systems.



MICHAEL COBB

Michael Cobb is an engineer in Walter P Moore's Diagnostics Group. His experience focuses on the field of building enclosure consulting and restoration engineering. Cobb's expertise includes evaluating and designing repairs for distress related to

precast facades, concrete structures, and roofing systems. He is a certified Part 107 drone pilot. He has also developed work scopes, repair details, repair procedures, and technical specifications for waterproofing and structural restoration and rehabilitation projects.

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