Advancing Automated Building Inspection: A BIM and GSD Integrated Framework for UAV Applications

Emadaldeen Benshaaban[1], Po-Han Chen[2], Shahinuzzaman[3]

Gina Cody School of Engineering and Computer Science, Concordia University, Canada
Emadaldeen.Benshaaban@Concordia.ca, pohan.chen@concordia.ca, s_sujon@live.concordia.ca

Abstract –

Unmanned Aerial Vehicles (UAVs) have become indispensable for building inspections, offering safer, more efficient, and automated alternatives to traditional manual methods. However, current approaches often rely on predetermined inspection parameters, such as fixed distances, without adequately aligning with specific inspection goals or ensuring consistent data quality. This paper presents a novel methodology that addresses these challenges by integrating Building Information Modeling (BIM) and Ground Sampling Distance (GSD) into the inspection planning process. BIM is leveraged to automate the generation of Field of Views (FoVs) and viewpoints, significantly reducing human intervention and ensuring precise coverage of inspection areas. GSD is utilized to determine the optimal distance between the UAV and the surface, guaranteeing that collected data meets predefined objectives, such as detecting fine defects. To further enhance efficiency, a Genetic Algorithm (GA) is employed to optimize the flight path, minimizing travel distance while maintaining comprehensive coverage of all required areas. While the methodology is developed primarily for building inspections, it is scalable and adaptable to other infrastructure types, demonstrating its versatility in diverse scenarios. By combining BIM-based automation, GSD-driven planning, and advanced optimization techniques, this work provides a robust solution for automated, efficient, and high-quality UAV-enabled inspections for future innovations in automated inspection systems.

Keywords –

Building Inspection; Unmanned Aerial Vehicles (UAVs); Ground Sampling Distance (GSD); Field of View (FoV)

1 Introduction

Infrastructure inspections, particularly for high-rise buildings, are essential for ensuring public safety and maintaining structural integrity. Traditional visual inspection methods have been the primary approach for identifying surface defects such as cracks, spalling, and corrosion due to their simplicity and accessibility [1]. However, these methods are often subjective, time-intensive, and risky for inspectors, especially when accessing high-rise structures or geometrically complex components [2]. Moreover, manual inspections frequently rely on an inspector's expertise and judgment, leading to inconsistencies and potential inaccuracies [3]. These challenges highlight the urgent need for more reliable and efficient solutions. Unmanned Aerial Vehicles (UAVs) have emerged as a transformative tool in building inspections, offering advantages such as enhanced safety, efficiency, and accessibility. By utilizing UAVs, inspectors can reduce physical risks, streamline data collection, and minimize disruptions to building operations. Despite their potential, current UAV-enabled inspection methodologies face notable challenges, including reliance on fixed inspection parameters and limited integration of specific data quality goals [4]. Most existing approaches employ arbitrary distances for data collection without scientific justification, which can compromise the accuracy and resolution of inspection data. Furthermore, these approaches often lack automation in critical stages, such as generating inspection viewpoints and planning efficient flight paths [5]. To address these challenges, this study proposes an autonomous UAV-based framework specifically designed for façade defect inspection, focusing on the detection of surface cracks and corrosion. Unlike general UAV-based reality capture for progress monitoring or 3D reconstruction, our approach ensures precise defect visibility by optimizing data collection based on Ground Sampling Distance (GSD). The framework integrates GSD calculations with UAV flight planning to guarantee that surface details are captured at the required resolution for defect identification. Automation and optimization techniques, including advanced algorithms for flight path planning, are integrated to streamline the process and reduce human intervention.

The remainder of this paper is organized as follows: Section 2 provides a comprehensive review of the existing literature on UAV-based inspections, emphasizing current advancements and challenges. Section 3 details the proposed methodology, outlining its key components and implementation. Lastly, the conclusion discusses the findings of this study and highlights directions for future work.

2 Literature Review

2.1 UAV-Based Building Inspections

The advent of UAVs has revolutionized the field of building inspections by offering a safer, faster, and more cost-effective alternative to traditional methods. UAVs are particularly advantageous in inspecting high-rise structures, complex geometries, and hazardous environments, where manual inspections pose significant risks. Equipped with advanced sensors and cameras, UAVs can capture high-resolution data for defect detection and structural analysis. Studies such as Rakha and Gorodetsky [6] emphasize the potential of UAVs in automating building inspections, particularly in capturing data for damage detection. They outline the benefits of UAVs in reducing human error and operational costs while enhancing the accuracy of data collection processes. Kerle et al. [7] highlight the integration of AI and machine learning algorithms with UAVs to process large datasets and automate the identification of structural damage. Their work underscores the transformative potential of UAVs when combined with intelligent systems to achieve fully autonomous inspection workflows. Recent studies have introduced optimization techniques to improve UAV-based reality capture plans. Ibrahim et al. [8] proposed a set of metrics to evaluate the effectiveness of UAV-based image capture for construction monitoring, focusing on visual coverage, resolution, and viewpoint orientation. Their later work [9] presented a multi-objective optimization model for improving reality capture plans, integrating flight path adjustments based on redundant observations and 3D reconstruction stability. While these studies introduced systematic UAV capture planning methods, they primarily optimize for construction progress monitoring, focusing on improving overall visual data collection efficiency.

2.2 Challenges in Current UAV-Based Inspection Methods

Despite the numerous advantages, UAV-based inspections face several challenges that limit their widespread adoption. A critical issue is the dependence on operator skills for flight path planning and data collection, which often leads to inconsistent coverage. Additionally, environmental factors such as wind, lighting, and weather conditions can significantly affect data quality. Feroz and Abu Dabous[10] identify key limitations in UAV-based inspections, such as the inefficiency of flight paths and the need for manual intervention in data collection. They argue that the lack of standardized protocols for UAV inspections contributes to inconsistencies across projects. Similarly, Mader and Westfeld [11] discuss the challenges of using UAVs in varying lighting and weather conditions, emphasizing the importance of robust data processing algorithms to mitigate these effects. Another significant challenge is the integration of UAV data into existing inspection workflows. The large volume of data collected by UAVs often requires extensive post-processing, which can delay decision-making. Addressing these challenges necessitates advancements in automation, optimization, and data integration.

2.3 Role of BIM in UAV-Driven Inspections

Building Information Modeling (BIM) has emerged as a powerful tool to enhance UAV inspections by providing a digital representation of structures. BIM facilitates automated planning of inspection paths and the overlay of inspection data onto structural models, enabling more efficient defect identification. Tan and Zhou [12] demonstrate how BIM can optimize UAV flight paths to ensure complete coverage of building surfaces. By integrating UAV data into BIM, they propose a system that reduces human intervention and improves data accuracy. This integration is particularly valuable in large-scale projects, where manual inspection planning is impractical. Feroz and Abu Dabous [13] highlight the potential of BIM to streamline data analysis by integrating inspection results with structural models. They argue that BIM not only improves data visualization but also aids in predictive maintenance by identifying areas prone to future damage. Despite these advantages, the seamless integration of UAVs and BIM remains challenging, requiring advanced data fusion techniques.

2.4 Ground Sampling Distance (GSD) in Data Collection

Ground Sampling Distance (GSD) can play a critical role in UAV-based inspections by determining the spatial resolution of captured images. High-resolution data is essential for accurate defect detection, but achieving optimal GSD often requires balancing flight altitude, speed, and camera settings. Mader and Westfeld [14] explore the impact of GSD on the accuracy of structural analyses. Their study shows that lower GSD values result in higher-resolution images, which are critical for identifying small defects. However, achieving low GSD often necessitates slower flight speeds and lower altitudes, which can increase inspection time and costs. The study by Kerle et al [15] highlights the need for adaptive GSD settings to optimize data collection across varying structural features. They propose dynamic adjustments to UAV flight parameters based on the complexity of the structure being inspected, ensuring both efficiency and data quality.

2.5 Optimization Algorithms in UAV Inspections

Optimization algorithms are critical for enhancing the efficiency and effectiveness of UAV inspections. Techniques such as Genetic Algorithms (GAs), Particle Swarm Optimization (PSO), and neural networks have been widely applied to optimize flight paths and reduce redundant data collection. Liu et al [16] present a framework for automated UAV-based inspections using optimization algorithms. Their work demonstrates how GAs can minimize flight time while ensuring comprehensive coverage of building façades. The framework also incorporates collision avoidance mechanisms, enhancing operational safety. Tan and Zou [17] explore the integration of edge computing with optimization techniques to enhance data processing efficiency. By processing data in real-time during inspections, their approach reduces the need for extensive post-processing and accelerates decision-making. The reviewed literature underscores the growing reliance on UAVs for building inspections, driven by their ability to enhance safety, efficiency, and precision. Despite notable advancements in integrating UAVs with BIM and optimization techniques, challenges such as inconsistent data quality, limited automation, and better adaptability to structural complexities remain. Research into optimizing Ground Sampling Distance (GSD) and leveraging advanced algorithms, such as Genetic Algorithms and real-time edge computing, provides promising pathways to overcome these issues. This study seeks to address these gaps by developing a robust, automated framework that integrates UAVs, BIM, GSD, and optimization strategies, thereby advancing the state of the art in building inspection methodologies.

3 Methodology

This study proposes a framework for UAV-based building inspections. It is designed to automate and optimize the inspection process while considering external environmental constraints that may impact UAV operations. The framework integrates Building Information Modeling (BIM), Ground Sampling Distance (GSD) calculations, environmental condition assessment, and optimization techniques to ensure efficient, adaptable, and high-quality inspection coverage.

3.1 Framework for Automated UAV-Based Building Inspection

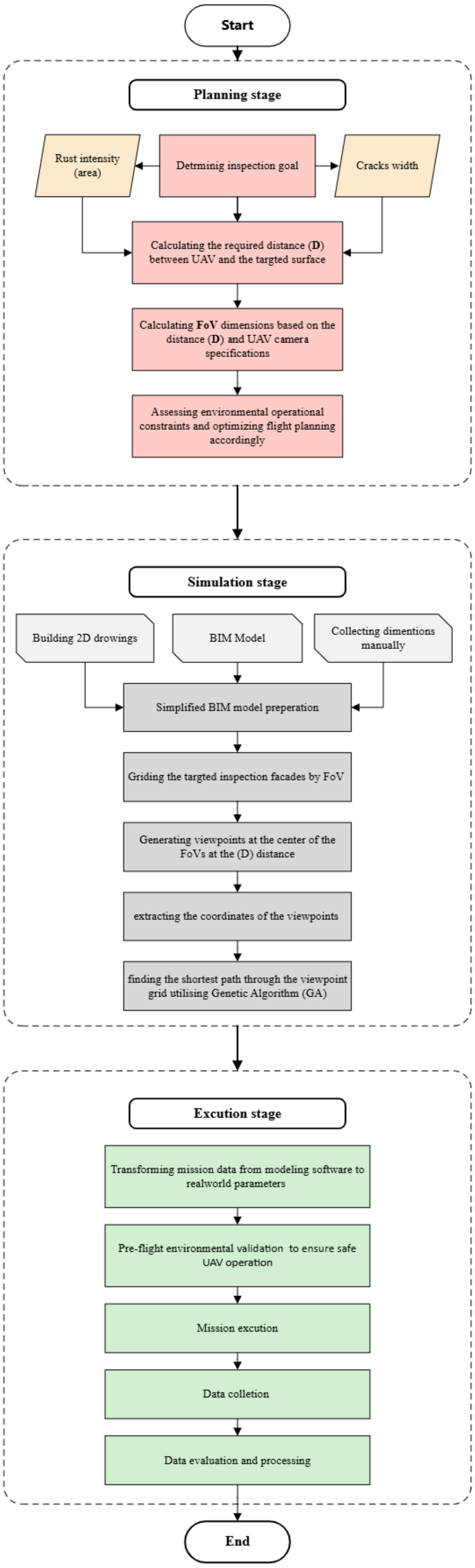
The framework is structured into three key stages: Planning, Simulation, and Execution, as shown in Figure 1. Each stage incorporates systematic processes to enhance accuracy and efficiency while adapting to real-world environmental conditions.

3.1.1 Planning Stage: The planning stage is crucial for defining inspection objectives and determining UAV flight parameters. The key components include:

a) *Defining Inspection Goals*: The UAV inspection is designed to detect surface defects such as cracks and corrosion while ensuring optimal data quality. *b) Calculating Required Distance (D):* to derive a generic equation for calculating the required distance between a UAV and a targeted surface based on inspection goals, we need to know all the parameters involved, understand how they affect the distance (D), and learn how to obtain them. The parameters influencing UAV distance can be classified into three categories, as detailed in Table 1. Deriving the final equation for D can be summarised in two simple steps. Step 1: *Relationship between GSD and sensor parameters:* Ground Sampling Distance (GSD) can be defined as the real-world size of one pixel in an image captured by a camera. It represents the spatial resolution of the image and determines the level of detail that can be captured from the ground [18].

Table 1. Parameters influence the distance between a UAV and the targeted surface

1- Inspection Requirements
GSD_r: Desired Ground Sampling Distance (mm/pixel). Figure 2
R_c: Crack width resolution requirement (mm).
FoV_w: Field of view width (mm). Figure 2
FoV_h: Field of view height (mm). Figure 2
2- Lens Parameters
f: Focal length of the camera (mm).
3- Sensor Parameters
S_w: Sensor width (mm).
S_h: Sensor height (mm).
P_x: Sensor resolution width (pixels).
P_y: Sensor resolution height (pixels).



As (GSD) is a function of the sensor size, resolution, and flight distance, it can be expressed mathematically:

$$\text{GSD} = \frac{Sw * D}{Px * f} \quad (1)$$

rearranging the equation (1) for D

$$\text{D} = \frac{GSD * Px * f}{Sw} \quad (2)$$

Step 2: *Incorporating Desired GSD and Crack Resolution:*

The desired GSD (GSD_r) is defined based on the inspection requirement for crack detection (R_c). To detect cracks of width (R_c), the resolution per pixel must satisfy:

$$GSD_r = R_c$$

Substituting GSD_r into the equation (2):

$$\boxed{\text{D} = \frac{Rc * Px * f}{Sw}} \quad (3)$$

c) Calculating FoV Dimensions: The Field of View (FoV) is calculated based on the camera's specifications and the desired distance (D). This ensures that the UAV captures an adequate area of the surface in each frame, balancing coverage with image resolution.

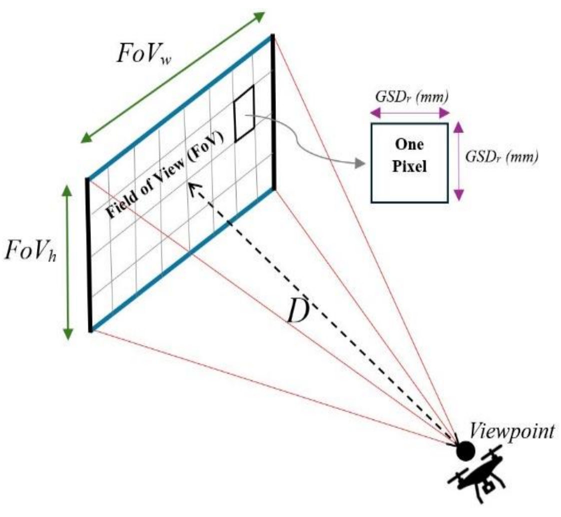


Figure 2. Field of view details, and GSD_r

d) Assessing Environmental Constraints: Environmental factors such as wind speed, temperature, lighting conditions, and GPS accuracy can significantly impact UAV stability and data quality; therefore, these variables are carefully considered during the planning phase. Wind speed constraints are analyzed to ensure stable flight, while lighting conditions are assessed to optimize visibility and defect detection. Temperature variations are considered, as extreme conditions can affect battery performance. Additionally, GPS accuracy is evaluated to minimize navigational errors.

3.1.2 Simulation Stage: This stage involves virtually preparing the inspection environment and optimizing the UAV's flight path. It begins with creating a simplified BIM model of the targeted building by removing unnecessary architectural details from the facades included in the original BIM. In cases where a BIM model is unavailable for the building, the simplified model can be constructed using 2D building drawings or by manually collecting the required measurements. *Next Step:* Gridding the Inspection Facades: The targeted facades for inspection are segmented into a grid based on the calculated Field of View (FoV) dimensions. This segmentation ensures systematic coverage of the entire surface area, as illustrated in Figure 3. The FoVs can be distributed on the facades with or without overlapping, depending on dimensions and inspection requirements. Once the grid is established, viewpoints are generated at the center of each FoV, positioned at the calculated distance (D). These viewpoints act as reference points for precise UAV positioning during the inspection. It is important to note that both the grid creation for FoVs and the generation of viewpoints have been automated using Autodesk Dynamo software. The last step in the simulation stage is the flight path optimization. There are several methods and techniques for path planning; however, in this study, a Genetic Algorithm (GA) is employed to determine the shortest and most energy-efficient path through the grid of viewpoints. This optimization minimizes UAV flight time and energy consumption while ensuring full coverage of the building façades. Figure 4 illustrates the optimal path obtained using GA.

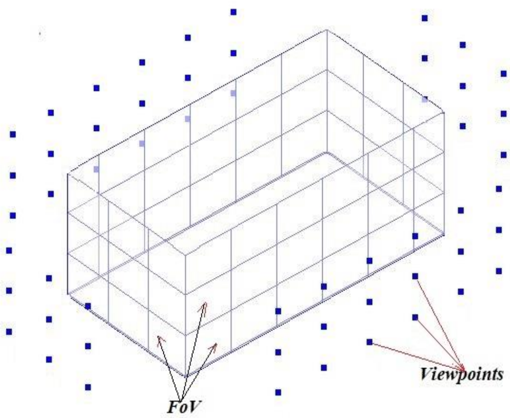


Figure 3. Griding the targeted facades and generating viewpoints at the desired distance

While the proposed framework ensures complete coverage in simulation, real-world conditions introduce uncontrollable variables such as UAV stability, environmental disturbances, and GPS accuracy, which may impact actual coverage. Therefore, a field experiment is planned to validate the methodology in real-world conditions and assess its effectiveness in achieving comprehensive façade inspection coverage.

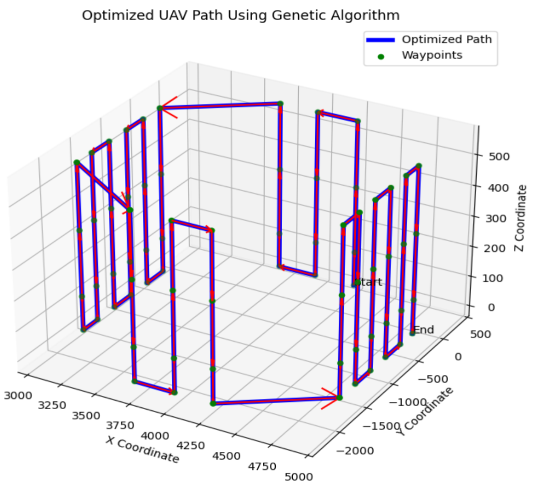


Figure 4. Optimized path planning using GA

3.1.3 Execution Stage: The execution stage translates the simulated flight plan into real-world UAV operations, ensuring reliable and environmentally adaptive data collection. This phase incorporates real-time validation and adjustments to maintain data accuracy and operational efficiency. The main steps are: (a) Mission Data Transformation: Data from the simulation stage, including waypoint (as same as viewpoints) coordinates and optimized flight paths, is transformed into real-world mission parameters compatible with UAV navigation systems. (b) Pre-Flight Environmental Validation and Adaptation: Before takeoff, real-time environmental conditions such as wind speed, lighting, and GPS stability are assessed. If any parameter exceeds operational thresholds, indicating a potential disruption, the operation is cancelled to ensure safety and data integrity. While such cancellations are rare, they are necessary to prevent compromised results and ensure mission reliability. (c) Mission Execution and Data Collection: The UAV executes the inspection mission based on the predefined flight path, capturing images and other required data for each FoV. (d) Data Evaluation and Processing: The collected data should be processed to extract actionable insights. This includes assessing rust intensity, crack width, and other structural defects.

4. Conclusion and Future Work

This study presents an automated framework for UAV-based building inspections, integrating Building Information Modeling (BIM), Ground Sampling Distance (GSD)-driven planning, and optimization algorithms. While the framework has yet to be experimentally validated, its design demonstrates significant potential to enhance inspection accuracy, operational efficiency, and scalability. The key contribution of this work is the development of a GSD-based equation to calculate the required distance (D) between the UAV and the targeted surfaces. This ensures high-resolution data collection tailored to specific defect detection needs, such as crack width and rust intensity. Additionally, the framework incorporates: (1) Automation of inspection parameters, including

Fields of View (FoVs) and viewpoints, to reduce human intervention and enable systematic and precise surface coverage. (2) The use of Genetic Algorithms (GA) to optimize UAV operations by minimizing travel time and energy consumption, enhancing inspection efficiency as part of the overall framework design. By combining these elements, the proposed framework provides a robust and adaptable solution for automated UAV-enabled building inspections, laying the groundwork for future innovations in infrastructure monitoring. While simulation results demonstrate full coverage of the inspection area, a future case study will be conducted to validate these findings in real-world conditions, accounting for potential operational constraints.

Future experiments will focus on validating these capabilities in real-world settings. Additionally, further research will explore the integration of real-time adaptive algorithms and AI-driven defect detection systems to enhance the framework's robustness and usability under varying environmental conditions.

5. References:

[1] H. Liang, S. C. Lee, W. Bae, J. Kim, and S. Seo, "Towards UAVs in Construction: Advancements, Challenges, and Future Directions for Monitoring and Inspection," Mar. 01, 2023, *Multidisciplinary Digital Publishing Institute (MDPI)*. doi: 10.3390/drones7030202.

[2] I. Jeelani and M. Gheisari, "Safety Challenges of UAV Integration in the Construction Industry: Focusing on Workers at Height," 2022. Accessed: Jan. 05, 2025. [Online]. Available: https://www.cpwr.com/wp-content/uploads/SS2022-UAV-safety-integration.pdf?utm_source=chatgpt.com

[3] H. Shin, J. Kim, K. Kim, and S. Lee, "Empirical Case Study on Applying Artificial Intelligence and Unmanned Aerial Vehicles for the Efficient Visual Inspection of Residential Buildings," *Buildings*, vol. 13, no. 11, Nov. 2023, doi: 10.3390/buildings13112754.

[4] V. Margolin, "Drone Inspections: A Comprehensive Guide," https://www.energy-robotics.com/post/drone-inspections-a-comprehensive-guide?utm_source=chatgpt.com.

[5] H. Hamledari, S. Davari, S. O. Sajedi, P. Zangeneh, B. Mccabe, and M. Fischer, "UAV-enabled Site-to-BIM Automation: Aerial Robotic-and Computer Vision-based Development of As-Built / As-is BIMs and Quality Control," 2018.

[6] T. Rakha and A. Gorodetsky, "Review of Unmanned Aerial System (UAS) applications in the built environment: Towards automated building inspection procedures using drones," Sep. 01, 2018, *Elsevier B.V.* doi: 10.1016/j.autcon.2018.05.002.

[7] N. Kerle, F. Nex, M. Gerke, D. Duarte, and A. Vetrivel, "UAV-based structural damage mapping: A review," Dec. 26, 2019, *MDPI AG*. doi: 10.3390/ijgi9010014.

[8] A. Ibrahim, M. Golparvar-Fard, and K. El-Rayes, "Metrics and methods for evaluating model-driven reality capture plans," *Computer-Aided Civil and Infrastructure Engineering*, vol. 37, no. 1, pp. 55–72, Jan. 2022, doi: 10.1111/mice.12693.

[9] A. Ibrahim, M. Golparvar-Fard, and K. El-Rayes, "Multiobjective Optimization of Reality Capture Plans for Computer Vision–Driven Construction Monitoring with Camera-Equipped UAVs," *Journal of Computing in Civil Engineering*, vol. 36,

no. 5, Sep. 2022, doi: 10.1061/(asce)cp.1943-5487.0001032.

[10] S. Feroz and S. A. Dabous, "Uav-based remote sensing applications for bridge condition assessment," May 01, 2021, *MDPI AG*. doi: 10.3390/rs13091809.

[11] D. Mader, R. Blaskow, P. Westfeld, and C. Weller, "Potential of UAV-Based laser scanner and multispectral camera data in building inspection," in *International Archives of the Photogrammetry, Remote Sensing and Spatial Information Sciences - ISPRS Archives*, International Society for Photogrammetry and Remote Sensing, 2016, pp. 1135–1142. doi: 10.5194/isprsarchives-XLI-B1-1135-2016.

[12] Y. Tan, S. Li, H. Liu, P. Chen, and Z. Zhou, "Automatic inspection data collection of building surface based on BIM and UAV," *Autom Constr*, vol. 131, Nov. 2021, doi: 10.1016/j.autcon.2021.103881.

[13] N. Kerle, F. Nex, M. Gerke, D. Duarte, and A. Vetrivel, "UAV-based structural damage mapping: A review," Dec. 26, 2019, *MDPI AG*. doi: 10.3390/ijgi9010014.

[14] D. Mader, R. Blaskow, P. Westfeld, and C. Weller, "Potential of UAV-Based laser scanner and multispectral camera data in building inspection," in *International Archives of the Photogrammetry, Remote Sensing and Spatial Information Sciences - ISPRS Archives*, International Society for Photogrammetry and Remote Sensing, 2016, pp. 1135–1142. doi: 10.5194/isprsarchives-XLI-B1-1135-2016.

[15] N. Kerle, F. Nex, M. Gerke, D. Duarte, and A. Vetrivel, "UAV-based structural damage mapping: A review," Dec. 26, 2019, *MDPI AG*. doi: 10.3390/ijgi9010014.

[16] B. T. Wang and C. M. Wang, "Advances in 21st Century Human Settlements Automating Cities Design, Construction, Operation and Future Impact." [Online]. Available: http://www.springer.com/series/13196

[17] Y. Tan, W. Yi, P. Chen, and Y. Zou, "An adaptive crack inspection method for building surface based on BIM, UAV and edge computing," *Autom Constr*, vol. 157, Jan. 2024, doi: 10.1016/j.autcon.2023.105161.

[18] B. Felipe-García, D. Hernández-López, and J. L. Lerma, "Analysis of the ground sample distance on large photogrammetric surveys," *Applied Geomatics*, vol. 4, no. 4, pp. 231–244, Dec. 2012, doi: 10.1007/s12518-012-0084-2.