Automated Unmanned Aerial Vehicle (UAV) Based Condition Assessment of Blue-Green Infrastructure: Application to Green Roofs

Évaluation automatisée de l'état des infrastructures bleu-vert par véhicule aérien sans pilote (UAV) : application aux toitures végétalisées

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RÉSUMÉ

Les infrastructures bleues et vertes (BGI) sont de plus en plus déployées pour atténuer les impacts du changement climatique en milieu urbain, mais leur suivi à long terme demeure difficile avec des inspections manuelles coûteuses et peu scalables. Cette étude propose une chaîne d'évaluation automatisée combinant imagerie par drone, détection d'objets par apprentissage automatique, analyse multispectrale de la végétation et interprétation assistée par un modèle de langage. Des orthomosaïques RGB et multispectrales haute résolution sont analysées via un modèle Mask R-CNN afin d'identifier les contours des toitures végétalisées et les modes de défaillance courants, tandis que des indicateurs NDVI quantifient l'état de la végétation. Le modèle de langage synthétise ensuite les résultats structurels et végétatifs dans un diagnostic standardisé. Une démonstration préliminaire fondée sur des images UAV du Brandebourg confirme la faisabilité de l'approche et son potentiel pour des évaluations rapides et non invasives. Les prochaines applications sur des jeux de données de Malmö et Berlin permettront de valider la précision de détection et d'examiner la pertinence de cette méthode pour une gestion et une maintenance à grande échelle des BGI.

ABSTRACT

Blue-Green Infrastructure (BGI) is increasingly deployed to mitigate climate-change impacts in cities, yet its long-term functionality is difficult to monitor with conventional, manual inspections. This study presents an automated workflow combining UAV-based imaging, machine-learning object detection, multispectral vegetation analysis and AI-assisted interpretation for assessing the condition of green roofs. High-resolution RGB and multispectral mosaics are analysed using a Mask R-CNN model to identify roof boundaries and typical failure modes, while NDVI indicators quantify vegetation health. A large language model then synthesizes structural and vegetative findings into standardized diagnostic outputs. A preliminary demonstration with UAV imagery from Brandenburg (Germany) confirms the feasibility of the workflow and its potential for rapid, non-invasive assessments. Upcoming validation using datasets from Malmö and Berlin will evaluate detection accuracy and examine the applicability of this approach for scalable BGI asset management and maintenance planning.

KEYWORDS

AI, Blue-Green Infrastructure, Failure mode, Maintenance, UAV

1 MOTIVATION & INTRODUCTION

Urban areas are increasingly exposed to climate-change impacts such as heavy rainfall and heatwaves. In response, cities are expanding the use of decentralized Blue-Green Infrastructure (BGI), e.g. green roofs, swales and infiltration systems, to mitigate runoff, enhance cooling, and support biodiversity. However, ensuring the long-term functionality of these distributed assets remains challenging. A recent survey conducted within the INTERREG BSR project *City Blues* highlights persistent barriers to BGI asset management: (i) limited financial and human resources for operation and maintenance, (ii) practical difficulties in equipping already build BGI with monitoring devices, (iii) small, scattered deployed BGIs elements that makes high-tech continuous monitoring impractical, and (iv) the absence of standardized, scalable assessment methods. These findings are consistent with (Langeveld et al., 2022), who emphasize the lack of monitoring approaches that can support BGI deterioration models at city scale.

Existing monitoring approaches rely predominantly on manual inspections, which are resource-intensive, subjective and not easily applied at city scale. While Unmanned Aerial Vehicle (UAV) based remote sensing and AI-driven image analysis offer promising alternatives. Current applications typically address either vegetation health or structural condition, rarely both within an integrated, automated workflow. This reveals a research gap: the need for a non-invasive, scalable method to assess both vegetative and structural conditions of distributed BGIs such as green roofs.

To address this gap, this study proposes an automated UAV-based monitoring workflow combining object detection, multispectral imaging and AI-assisted interpretation. The workflow is designed for green roofs; however, due to pending data authorizations, its current demonstration uses UAV images from the Federal State of Brandenburg (Germany) to illustrate its functionality.

2 METHODOLOGY

2.1 Overview of the Workflow

The proposed workflow consists of four components: (i) UAV data acquisition and pre-processing, (ii) object detection of green roof boundaries and failure modes, (iii) vegetation index calculation and (iv) automated interpretation using an AI language model (see Figure 1).

This study presents the general functionality of the workflow. While it is designed for application to green roofs, pending data authorizations mean that the current demonstration relies on UAV imagery from Brandenburg.

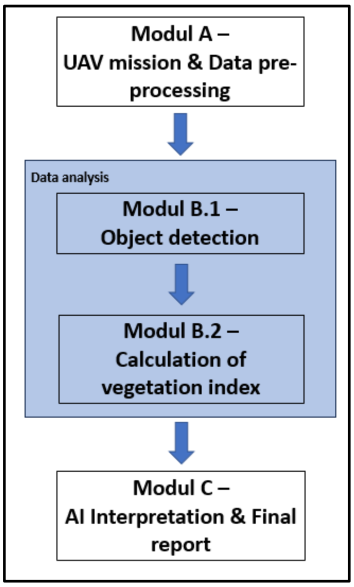

Figure 1 UAV workflow

2.2 UAV mission and Pre-processing

UAV flights were conducted using a DJI Mavic 3M equipped with a 20 MP RGB camera and 5 MP multispectral sensors. Following acquisition, individual images were processed in the open-source photogrammetry software *WebODM* to generate high-resolution RGB and multispectral orthomosaics. These mosaics form the spatial basis for object detection and vegetation analysis.

2.3 Data Analysis

The data analysis comprises two main steps: first, detecting relevant objects such as green roof boundaries and failure modes; and second, calculating vegetation indices for the identified roof areas.

2.3.1 Object Detection

Object detection was implemented in a Python environment using the *Mask R-CNN* architecture as provided by the Detectron2 framework (Wu et al., 2019). Training data consisted of manually annotated examples of green areas (trees) and objects, prepared using *Roboflow* and trained via *Google Colab*. The model identifies green-extents (trees) and objects, generating segmentation masks used in subsequent vegetation analysis.

2.3.2 Calculation of Vegetation Index

For all detected green areas, vegetation condition is assessed through the *Normalized Difference Vegetation Index (NDVI)*, derived from the RED and NIR bands of the multispectral imagery.

$$NDVI = \frac{NIR - RED}{NIR + RED}$$

The workflow computes both spatially explicit NDVI maps and summary metrics, including mean NDVI and the proportion of roof area below a defined threshold (e.g., NDVI < 0.2). These indicators support the identification of potential vegetation stress, consistent with recent applications in green roof monitoring (Liao et al., 2025).

2.4 AI Interpretation & Compiling of Report

In the final step, a large language model (LLM) interprets the detected objects and vegetation indicators following predefined prompts to ensure consistent terminology and assessment criteria. The model synthesizes structural findings and vegetation health indicators into an automated report.

3 PRELIMINARY RESULTS

Due to pending data authorizations for green roofs in Malmö and Berlin, the current demonstration of the workflow is based on UAV imagery from Brandenburg (Germany). These preliminary results focus on illustrating the technical functionality of the automated assessment chain. Results based on green roof data can be expected in June 2026.

3.1 Data analysis

3.1.1 Object Detection

The Mask R-CNN model successfully detected the previously annotated objects (Figure 2). The segmentation masks produced by the model enable the isolation of the objects for further analysis. While quantitative performance metrics will be derived once annotated green-roof datasets become available, the initial results indicate robust delineation of boundaries.

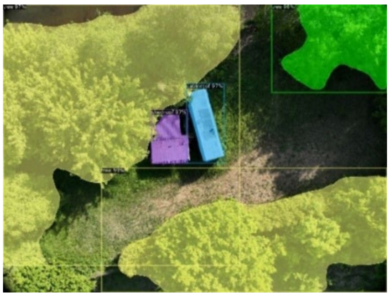

Figure 2 UAV image with detected objects

3.1.2 Calculation of Vegetation Index

Using the segmentation masks, NDVI values were computed for each detected annotated green area, in this preliminary test, the trees. Figure 3 illustrates both the spatial distribution of NDVI and the resulting summary indicators, including mean NDVI and the proportion of pixels below the stress threshold (NDVI < 0.2). This combination of spatial and statistical outputs supports a rapid assessment of vegetation condition and highlights areas requiring closer inspection.

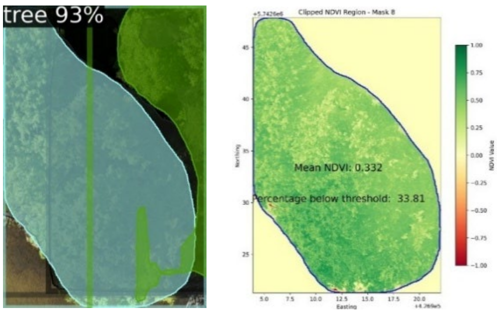

Figure 3 Detected object (tree) and Vegetation index

3.2 AI Interpretation & Compiling of Report

The LLM-based interpretation module integrates object detection outputs and vegetation indicators into a structured evaluation (Figure 4). The generated descriptions provide expert-style assessments of structural conditions and vegetation health and can highlight potential maintenance needs. These results demonstrate the feasibility of automating the interpretative step, which traditionally requires specialized expertise and significant manual effort.

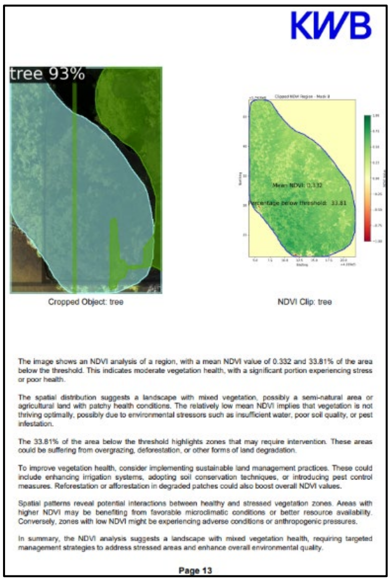

Figure 4 AI Interpretation of objects

3.3 Overall Demonstration

Together, these preliminary results demonstrate the functional integration of UAV sensing, object detection, vegetation analysis and AI-driven interpretation into a single workflow. Once applied to annotated green roof data from Malmö and Berlin, the system will allow quantitative validation of detection accuracy and support the evaluation of its applicability across different roof types and urban contexts.

4 CONCLUSIONS & OUTLOOK

This study introduces an automated workflow integrating UAV-based imaging, object detection, vegetation analysis, and AI-assisted interpretation for assessing the condition of green roofs. The preliminary demonstration using generic UAV data confirms the feasibility of the approach and its potential for rapid and non-invasive BGI assessment.

The next phase will apply the workflow to datasets from Malmö and Berlin, enabling quantitative validation against manual inspections and testing its robustness across different roof types and seasons.

Overall, the workflow represents a promising step toward scalable, data-driven monitoring strategies for urban BGI, with the potential to support municipalities and asset owners in more efficient and consistent maintenance planning.

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