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High-Resolution UAV-Derived 3D City Models Supporting Urban Seismic Resilience: A Case Study of Elin Pelin, Western Bulgaria

Tsvetelina Atanasova-Evdenova [1], Yana Lipiyska [1], Mihaela Kouteva-Guentcheva [1, 2], Lyubka Pashova [3, a)]

[1] *University of Architecture, Civil Engineering and Geodesy (UACEG), Hristo Smirnenski 1, 1046 Sofia, Bulgaria*
[2] *UACEG-NEEC – National Earthquake Engineering Centre, Bulgaria*
[3] *National Institute of Geophysics, Geodesy, and Geography – Bulgarian Academy of Sciences, Acad. Georgi Bonchev Bl. 3, 1113 Sofia, Bulgaria*

[a)] Corresponding author: lpashova@geophys.bas.bg

Abstract. Advancing urban seismic resilience in conditions of urbanisation increasingly relies on accurate, high-resolution, and up-to-date geospatial information describing the built environment. A high-resolution UAV 3D model serves as the foundational baseline for pre-seismic vulnerability mapping and provides an instant, highly accurate reference for rapid post-disaster damage assessment of any settlement. This study presents an RTK-supported UAV photogrammetric workflow for generating a high-resolution three-dimensional (3D) city model of Gara Elin Pelin, a representative peri-urban settlement in Western Bulgaria. Using a DJI Mavic 3M, 2,856 nadir images were acquired without ground control points and processed to produce a 1.28 cm/pixel orthomosaic, a dense point cloud exceeding 1.24 billion points, a textured 3D model, and a Digital Elevation Model (DEM). These datasets enable the extraction of key building and terrain attributes for building inventories, seismic exposure assessment, emergency planning, and post-earthquake damage assessment. The case study demonstrates that Bulgaria possesses the technical expertise and RTK-supported UAV capability required for high-resolution settlement (urban) mapping. A SWOT analysis and recommendations for integrating nadir and oblique UAV imagery outline future directions for strengthening settlement seismic resilience and the progressive implementation of Digital Building Logbooks (DBL). The proposed methodology offers a scalable and cost-effective solution for municipalities seeking to strengthen earthquake preparedness through high-resolution geospatial data.

Keywords: UAS; UAV; photogrammetry; 3d city settlement model; seismic resilience; urban resilience; GIS; Digital Building Logbook

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INTRODUCTION

Rapid, dense urbanization increases seismic vulnerability by concentrating populations in high-risk areas and outpacing the enforcement of building safety codes. Urban seismic resilience has become a central objective of contemporary disaster risk reduction, requiring cities not only to withstand earthquake impacts but also to prepare for,

respond to, and recover from seismic events effectively. Achieving this objective depends on reliable seismic hazard assessment together with accurate, up-to-date information on the built environment. In Bulgaria, demographic ageing, population decline, and ongoing population concentration in urban areas are reshaping the spatial distribution and seismic exposure of the built environment. Consequently, comprehensive geospatial datasets have become increasingly important for supporting seismic resilience, urban planning, emergency management, and evidence-based decision-making.

Recent advances in unmanned aerial systems (UASs), high-resolution digital photogrammetry, and geographic information technologies have transformed the collection of spatial information for disaster risk management. Compared with conventional surveying techniques, UAVs enable rapid, cost-effective, and highly detailed mapping while minimizing field operations and providing safe access to difficult or hazardous areas. High-resolution three-dimensional city models generated from UAV imagery represent an important source of information for seismic exposure assessment. Such models allow the extraction of geometric building parameters, support the creation of digital building inventories, improve emergency planning, and provide valuable baseline information for post-earthquake damage assessment. The objective of this study is to demonstrate a comprehensive UAV photogrammetric workflow for generating a high-resolution 3D city model of Gara Elin Pelin, located in Western Bulgaria, and to evaluate its potential contribution to urban seismic resilience.

UAV'S APPLICATIONS FOR URBAN SEISMIC RESILIENCE

UAV-derived 3D city models provide valuable spatial information that contributes to multiple components of urban seismic resilience, even though they do not directly represent the structural capacity of buildings. One of their primary applications is the development of high-resolution building inventories. Building footprints, heights, roof geometries, and spatial distribution can be automatically extracted and integrated into Geographic Information Systems (GIS) for seismic exposure assessment. These inventories provide essential input for estimating the potential consequences of future earthquake scenarios and identifying priority areas for risk mitigation [1, 2].

The generated models also enhance emergency preparedness by providing detailed three-dimensional visualization of the urban environment. They enable authorities to identify evacuation routes, emergency access corridors, temporary assembly areas, and locations where debris accumulation may obstruct rescue operations [3, 4].

Following an earthquake, the pre-event 3D model serves as a reliable reference for comparison with newly acquired UAV imagery. Such comparisons facilitate rapid damage identification, prioritization of field inspections, and more efficient allocation of emergency response resources. UAV-based photogrammetry has been widely recognized as an effective tool for rapid post-disaster mapping due to its high spatial resolution, flexibility, and rapid deployment [5, 6]. Furthermore, UAV-derived datasets can be integrated into municipal GIS and Digital Building Logbooks (DBLs), creating continuously updated digital records of the built environment. These interoperable databases support long-term monitoring, urban planning, infrastructure management, and disaster risk reduction while improving data accessibility for multiple stakeholders [7, 8].

Overall, the proposed workflow for generating 3D city models contributes to urban seismic resilience by enhancing situational awareness, strengthening emergency preparedness and response, and providing reliable geospatial information for evidence-based decision-making throughout the disaster management cycle [9, 10, 11].

For small towns characterized by low-rise buildings, ageing masonry construction, and uneven population distribution, neither nadir nor oblique UAV imagery alone is sufficient for reliable post-earthquake assessment. Nadir imagery provides rapid regional coverage and supports automated mapping, whereas oblique imagery captures facade damage, structural deformations, and other features that are frequently invisible from a vertical perspective. Their combined use significantly improves damage detection accuracy, the completeness of 3D reconstruction, and the quality of geospatial information available for emergency response, damage assessment, and recovery planning [5, 6, 12].

THE BULGARIAN CASE STUDY

Study Area

The site of Gara Elin Pelin, located approximately 25 km east of Sofia, was selected as the study area because it represents a Bulgarian peri-urban settlement characterized by a heterogeneous building stock, ongoing suburban development, and moderate seismic hazard. The area includes residential, commercial, and public buildings constructed over different historical periods, ranging from traditional masonry houses to reinforced concrete buildings

and newer residential developments. The housing stock in Elin Pelin Municipality is characterized by a clear dominance of buildings constructed between 1970 and 1990, accounting for approximately 45% of the total stock. The share of older buildings (pre-1970) remains significant (~25%), particularly in rural areas. Post-2000 construction represents approximately 20–25% of the housing stock, with a noticeable increase after 2010, driven by peri-urbanization processes related to the proximity of Sofia [13]. This diversity provides a representative environment for evaluating UAV-based three-dimensional reconstruction across different building typologies and roof geometries.

The study area, located near Elin Pelin in the Sofia seismic zone, falls within a region of moderate seismic hazard, characterized by reference peak ground acceleration values of approximately 0.15–0.23 g according to the national annex of Eurocode 8 [13]. For the Elin Pelin region, the reference peak ground acceleration is approximately 0.23–0.24 g (ground type A, 475-year return period), underscoring the importance of seismic preparedness in local urban planning. The predominance of buildings constructed before the widespread adoption of modern seismic design provisions underscores the importance of developing accurate digital building inventories.

The study area, centered near 42.6222° N, 23.5800° E, includes a cluster of buildings of varying construction types and roof geometries, chosen specifically to test the reconstruction approach across structurally diverse targets. No ground control points were used; the survey relied entirely on Real-time kinematic (RTK)-corrected onboard positioning, with the resulting accuracy detailed in the section below. An orthomosaic of the study area near Elin Pelin railway station is shown in Figure 1. From a logistical and operational perspective, the site's compact urban layout, favourable conditions for RTK/GNSS signal reception, and proximity to Sofia allowed complete coverage in a single UAV mission, while the site itself remains representative of small towns across Bulgaria.

From a methodological perspective, the study area offers favourable conditions for evaluating high-resolution UAV photogrammetry. The combination of detached houses, low-rise apartment buildings, industrial facilities, transport infrastructure, vegetation, and open spaces enables assessment of the reconstruction workflow under varying geometric and environmental conditions. Furthermore, the relatively compact urban fabric enables complete coverage in a single UAV mission while producing datasets representative of many small- and medium-sized Bulgarian settlements.

Consequently, Gara Elin Pelin provides an appropriate pilot site for demonstrating how UAV-derived 3D city models can support digital building documentation, seismic exposure assessment, emergency planning, and the future development of DBL within the broader framework of urban seismic resilience.

Data Acquisition and Processing

Data acquisition and processing are performed according to the flowchart shown in Figure 1. Aerial data over the study area were acquired using a DJI Mavic 3M (M3M) UAS, operating its integrated RGB camera (12.29 mm true focal length, 5280 × 3956 px, pixel size 3.36 × 3.36 μm). The flight was planned as a standard orthomosaic (nadir) mission covering an area of 0.49 km², at a route altitude of 50 m above ground level, a flight speed of 10.6 m/s, and a course angle of 339°, yielding a planned ground sampling distance (GSD) of 1.34 cm/pixel. RTK positioning of the UAS was achieved through a connection to a D-RTK 3 mobile base station, whose reference point coordinates were determined beforehand using a Satlab/Hi-Target SL900 GNSS receiver, ensuring direct orientation of the acquired imagery without the need for ground control points.

A total of 2,856 images were collected and subsequently processed in Agisoft Metashape Professional (Version 2.2.1) [14]. Images were aligned at High accuracy in Metashape, with frontal overlap of 80% and side overlap of 70%. Alignment settings: generic and reference (source-based) preselection enabled; key point limit 40,000; tie point limit 4,000 per image. Camera calibration parameters were pre-calibrated for the M3M sensor and refined during bundle adjustment. Sparse point cloud generation resulted in 2,217,970 tie points (out of 2,393,674 candidate points), with an average point multiplicity of 5.15 and an initial RMS reprojection error of 0.863 px. The coordinate reference system (CRS) of the 3D model and the georeferenced orthomosaic is WGS 84 (EPSG:4326).

Following sparse cloud generation, the point cloud was refined through an iterative filtering procedure to improve geometric accuracy prior to dense reconstruction. First, points were filtered by Reconstruction Uncertainty, with the threshold lowered until values fell within the 20–40 range; no more than 10% of the total tie points were removed at this stage to avoid over-thinning. Camera alignment was then re-optimized. Points were then filtered by Reprojection Error, aiming to reduce the residual error to approximately 0.3, again removing no more than 10% of the remaining tie points to eliminate false matches. A second camera optimization was performed after this step to finalize the adjusted exterior and interior orientation parameters.

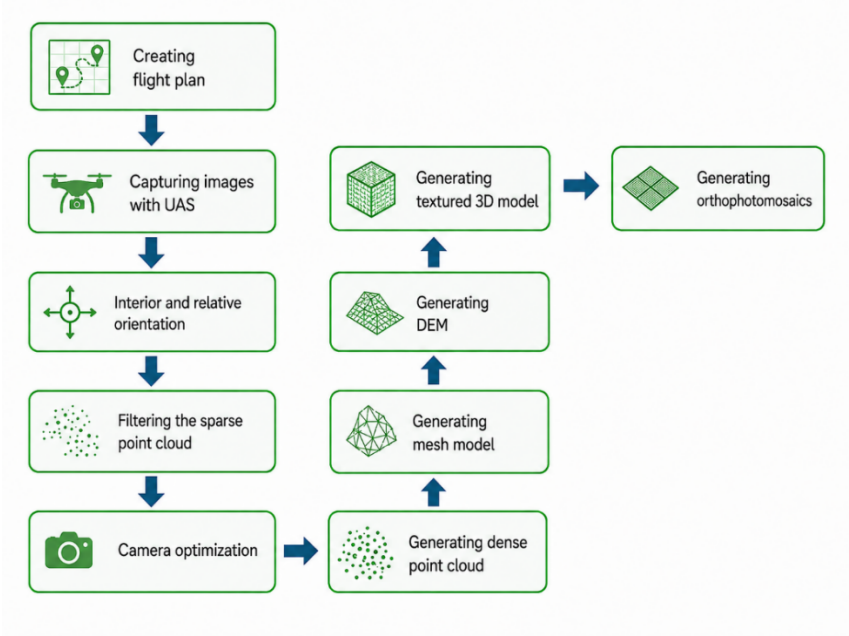


FIGURE 1. Capturing and processing UAS images.

Dense reconstruction was carried out at High quality, producing a dense point cloud of 1,241,538,969 points with a coordinate precision of 6.39 mm (Figure 2), along with some depth map samples in Figure 3.

FIGURE 2. Perspective views of the dense point cloud

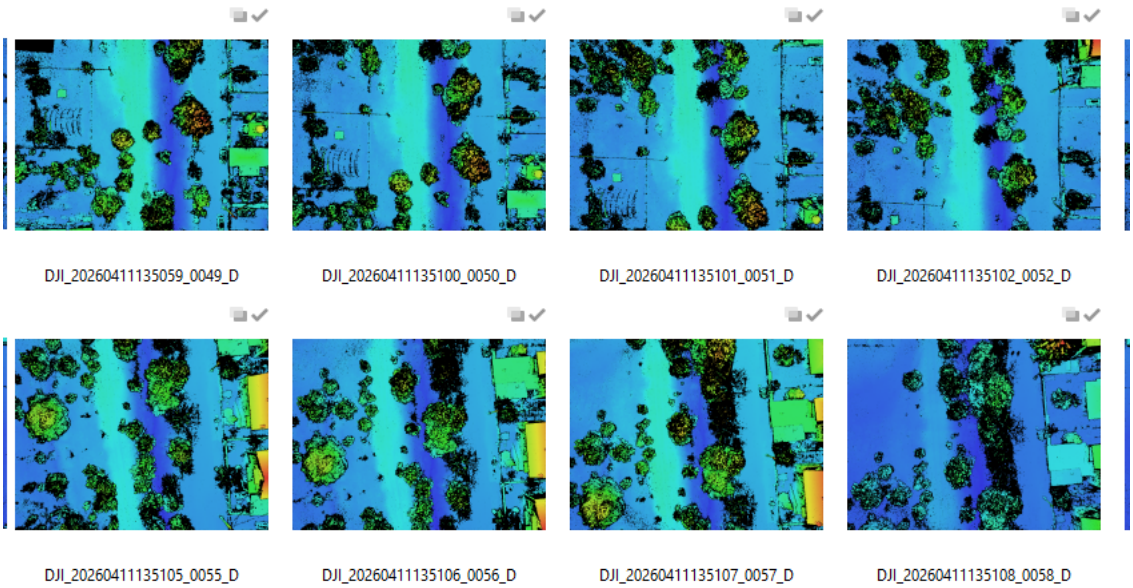
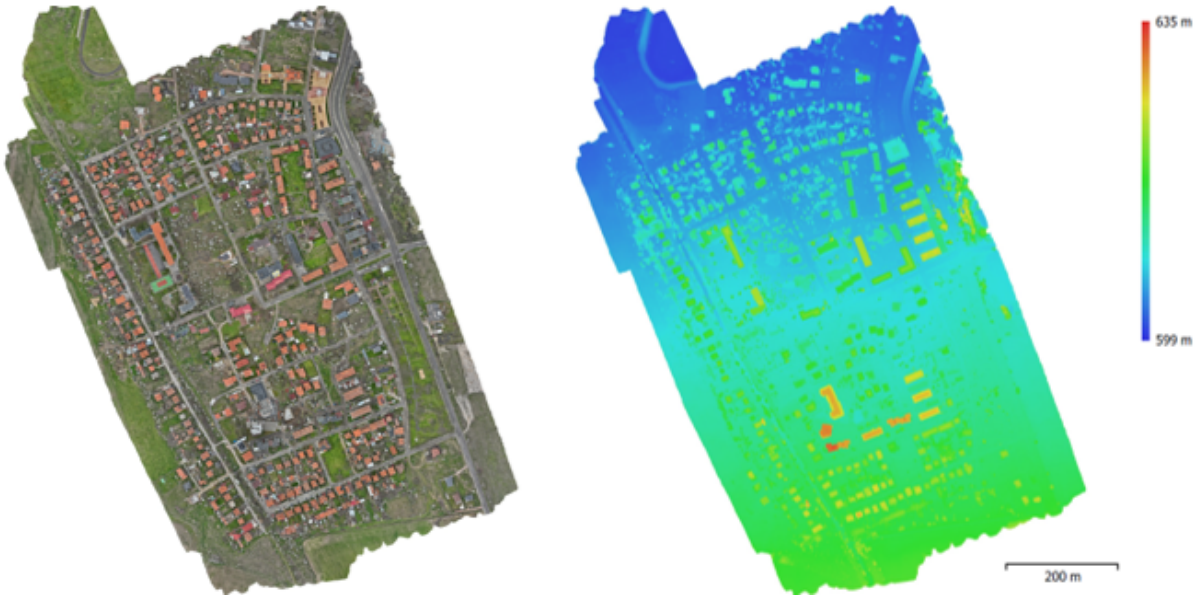


FIGURE 3. Sample depth maps used in dense point cloud generation.

A digital elevation model (DEM) was derived from the dense cloud at a resolution of 5.14 cm/pixel and a point density of 378 points/m², covering a final reconstructed area of 0.607 km² (Figure 4b).

The achieved ground resolution of the final orthomosaic (Figure 4a) was 1.28 cm/pixel, against the planned GSD of 1.34 cm/pixel, a difference of about 4–5%. This spatial resolution is consistent with normal variation in terrain relief and small deviations from the planned flight altitude.



(a) (b)

FIGURE 4. Orthomosaic (a) and DEM (b) of the study area near Elin Pelin railway station

DISCUSSION OF THE RESULTS

Contribution of the UAV-Derived Geospatial Data to Urban Seismic Resilience

The photogrammetric workflow (Figure 1) successfully produced a comprehensive set of high-resolution geospatial products describing the study area. Despite the absence of ground control points, RTK-supported image acquisition via a D-RTK 3 mobile base station enabled accurate direct georeferencing throughout the project. The dense point cloud contains more than 1.24 billion points and accurately represents terrain morphology, buildings, roads, vegetation, and other urban features. The resulting textured mesh preserves detailed roof structures and facade geometry, making it suitable for both visualization and quantitative measurements. The DEM provides detailed topographic information with a spatial resolution of 5.14 cm/pixel, while the orthomosaic achieved a final ground sampling distance of 1.28 cm/pixel, slightly exceeding the planned resolution. This level of detail enables precise identification of individual buildings and surrounding infrastructure.

The RTK-supported UAV survey produced centimeter-level geospatial datasets without ground control points while maintaining high geometric quality. The textured 3D model of the built environment enables extraction of key building and terrain attributes, including footprints, heights, roof geometry, road networks, open spaces, topography, and emergency access. Their applications extend beyond visualization to support building inventories, seismic exposure assessment, emergency planning, and post-earthquake response. Road networks, building outlines, and open or green spaces can be vectorized directly from the orthomosaic and combined with the DEM to identify slope-related constraints and obstacles along potential routes. Using this information, a simple route analysis in a GIS environment can outline an evacuation path from the residential area near Gara Elin Pelin to the nearest open green space suitable as a temporary assembly point in an emergency.

The generated geospatial datasets support multiple phases of the disaster management cycle [10] and can be integrated into broader digital resilience frameworks (Table 1).

TABLE 1. Geospatial datasets supporting multiple phases of the disaster management cycle.

Dataset	Potential applications for seismic urban resilience
Orthomosaic	Building inventory, exposure mapping, cadastral verification, evacuation planning, accessibility analysis
Dense point cloud	Building heights, roof geometry, terrain modelling, vegetation analysis, line-of-sight studies
3D textured model	Virtual building inspection, facade documentation, DBL, Digital Twins
DEM	Slope analysis, drainage, emergency accessibility, UAV mission planning
RTK georeferenced imagery	Multi-temporal monitoring, automated change detection, AI-based damage assessment
Complete project database	Municipal GIS, emergency management systems, civil protection planning, long-term resilience monitoring

Together, these datasets provide a reliable pre-earthquake digital baseline for comparison with post-event UAV surveys, enabling rapid identification of structural changes, debris, blocked transport corridors, and damaged infrastructure [5, 11]. Integration with GIS, BIM, DBLs, and future Digital Twin platforms supports continuous updating of urban information and evidence-based decision-making throughout the disaster management cycle [1, 7, 8]. In particular, ground and soil condition data, such as local soil classification, shear-wave velocity profiles, and liquefaction susceptibility, are needed to complement the geometric building and terrain data produced in this study, since seismic ground-motion amplification depends strongly on subsurface conditions that cannot be observed from aerial imagery alone.

The orthomosaic and the DEM created in this study are inherently compatible with global terrain datasets, such as the "USGS Global Vs30" global mosaic map, which is used as a proxy for seismic site conditions [15,16], since both can be aligned in a common geodetic coordinate system (WGS 84) within a GIS environment. Overlaying the high-resolution orthomosaic and building outlines onto a Vs30 raster map would allow each building or city (settlement) block to be assigned an indicative terrain class (e.g., NEHRP soil classes based on Vs30 thresholds), which would support first-order seismic microzonation of the study area. However, global Vs30 models are typically derived from approximate topographic slope indicators with a resolution of ~1 km, which is several orders of magnitude coarser than the centimeter-scale data from UASs presented here. Therefore, when assessing seismic risk at the building level, it would be useful to employ local geophysical measurements to refine the Vs30 estimate at the study area scale, with the DEM obtained via UAV providing the small-scale terrain data necessary for assessing ground response.

The proposed workflow (Figure 1) has several limitations. Dense vegetation and occluded facades may reduce reconstruction completeness, while weather conditions and aviation regulations constrain UAV operations. Although photogrammetric data accurately capture geometric characteristics, structural properties such as material strength, reinforcement details, and construction quality require complementary engineering investigations. Future developments may include AI-assisted feature extraction, semantic object classification, and integration with BIM, DBL, and Digital Twin platforms for real-time urban monitoring and seismic resilience.

An important outcome of the present study is that it demonstrates Bulgaria's existing technical capacity to acquire and process high-resolution RTK-supported UAV data for engineering applications. The successful implementation of the complete photogrammetric workflow confirms that trained specialists, commercially available UAV platforms, and established processing methodologies are already available for generating reliable geospatial datasets [17]. This technical readiness provides a practical basis for the gradual implementation of DBLs [18, 19], where UAV-derived orthomosaics, dense point clouds, and 3D city models can complement cadastral and building information throughout the building life cycle [19], The integration of these datasets with GIS and BIM environments would further strengthen urban seismic resilience by supporting continuously updated building records, improved exposure assessment, and evidence-based emergency management.

SWOT Analysis of the UAV Data Acquisition

A SWOT analysis of the implemented UAV data acquisition workflow is presented in Table 2 to assess its practical applicability. It identifies the principal technical strengths, operational limitations, development opportunities, and external factors influencing its application to urban seismic resilience. Relevant opportunities and threats for the practical implementation of the proposed workflow are presented in Table 3 (Pashova et al., 2026; these proceedings).

TABLE 2. SWOT analysis of the implemented UAV data acquisition workflow.

Strengths	Weaknesses
High spatial resolution (1.28 cm/pixel orthomosaic)	Nadir-only acquisition limits facade visibility
RTK positioning eliminated the need for ground control points	Structural properties cannot be inferred from geometry alone
Rapid acquisition over the entire study area	Dense vegetation may obscure building elements
More than 1.24 billion-point dense cloud	Processing requires high-performance computing resources
Accurate georeferencing suitable for GIS integration	Weather and illumination influence image quality
High-quality textured 3D model	Interior building damage cannot be observed

UAV data acquisition in urban environments is subject to both regulatory and technical constraints that shape mission planning. Under Bulgarian regulations, Open category operations are limited to a maximum altitude of 120 m above ground level (AGL), require the aircraft to remain within visual line of sight (VLOS) of the remote pilot, and prohibit flights over assemblies of people or within restricted airspace. Any operation exceeding these limits, flights above 120 m, beyond visual line of sight (BVLOS), or certain missions over densely built-up areas, requires prior authorization from the Bulgarian Civil Aviation Administration (BCAA) under the Specific category. Applicable UAS geographical zones must also be checked before each flight to ensure airspace compliance [20, 21]. Technical constraints add a further layer of complexity. Multirotor UAVs are limited by battery endurance, typically 20–40 minutes under favorable conditions, of which only 15–30 minutes remain usable for mapping once the mandatory safety reserve is deducted. As a result, covering large urban areas at high resolution generally requires several autonomous flights with battery swaps, followed by photogrammetric integration of the resulting datasets.

TABLE 3. Relevant opportunities and threats for the practical implementation of the proposed workflow.

Opportunities	Threats
Integration with DBLs	UAV flight restrictions in emergency situations
AI-assisted automatic damage detection	GNSS signal degradation in dense urban environments
Multi-temporal monitoring of urban change	Severe weather limiting UAV deployment
Integration with Digital Twins	Data management challenges due to very large datasets
Municipal resilience planning	Regulatory constraints on emergency UAV operations
National building inventory development	Cybersecurity and long-term data storage requirements

UAV surveys supporting urban seismic resilience in Bulgarian municipalities in the future are expected to combine nadir- and oblique-image acquisition [1,5,6]. Such an integrated approach provides comprehensive geometric documentation of buildings before earthquakes and significantly improves the identification of roof and facade damage after seismic events, thereby strengthening digital building inventories, DBLs, and informed emergency decision-making. A brief comparison of nadir and oblique UAV imagery for urban seismic resilience applications in small towns with ageing low-rise buildings is presented in Table 4.

CONCLUSIVE REMARKS

The presented methodological approach demonstrates that RTK-supported UAV photogrammetry can efficiently generate centimetre-level textured 3D city models without ground control points, providing an accurate digital representation of the built environment. The resulting orthomosaic, dense point cloud, 3D model, and DEM support the development of building inventory, seismic exposure assessment, emergency planning, and post-earthquake damage assessment. Beyond seismic applications, these datasets are also applicable to infrastructure management, cadastral updating, urban planning, and environmental monitoring.

The case study of Elin Pelin demonstrates that Bulgarian specialists already possess the technical expertise and operational capability to acquire and process high-resolution UAV data for the generation of detailed three-dimensional city models. This capability provides a practical foundation for the progressive implementation of DBL,

TABLE 4. Comparison of nadir and oblique UAV imagery for urban seismic resilience applications in small towns with ageing low-rise buildings.

Phase / Criterion	Pre-earthquake baseline documentation	Immediate post-earthquake survey	Pre-/post-earthquake comparison	Engineering damage assessment	Emergency response planning	GIS and DBL integration
Nadir imagery	Orthophotos, roof geometry, building footprints, streets, open spaces	Rapid identification of collapsed roofs, debris fields, blocked roads, inaccessible areas	Orthomosaic and DSM comparison for roof collapse and footprint changes	Limited capability for identifying facade mechanisms and vertical structural damage	Accessibility mapping, debris distribution, evacuation routes and temporary assembly areas	Orthophotos, DEM/DSM, accessibility layers and damage maps
Oblique imagery	Facades, chimneys, balconies, roof edges, masonry walls	Detection of facade cracks, wall tilting, out-of-plane failures and chimney collapse	Three-dimensional comparison of facade deformation and partial structural collapse	Detailed documentation of cracks, leaning walls, facade failures and partial collapse	Building-level prioritization of unsafe structures	Textured 3D models, facade inventories and building-level documentation
Relevance [a]	Creates a comprehensive digital baseline of vulnerable buildings for exposure assessment and future comparison [1, 2].	Combining nadir and oblique imagery improves damage detection, particularly for ageing masonry buildings where facade damage is poorly visible from nadir imagery [5, 6]	Supports rapid identification of earthquake-induced changes through multi-temporal analysis and prioritization of inspections [5, 6, 22-24]	Particularly suitable for unreinforced masonry, stone masonry, adobe and older reinforced concrete buildings frequently encountered in Bulgaria [3,4]	Improves operational planning, situational awareness and allocation of emergency resources during response operations [12]	Supports continuously updated municipal GIS, DBLs and future Digital Twins through interoperable geospatial information [7,8]
Indicative GSD	2–5 cm/pixel (urban inventory), 1–2 cm/pixel (priority buildings)	2–3 cm/pixel; ≤1.5 cm/pixel for detailed damage mapping	≤3 cm/pixel	0.5–2 cm/pixel	3–5 cm/pixel	2–5 cm/pixel (GIS); 1–2 cm/pixel (DBL) databases
Flight parameters	60–120 m AGL; forward overlap 75–85%; side overlap 65–75%	Nadir 60–100 m AGL; Oblique 30–70 m AGL; overlap ≥80/70%.	Repeat similar flight geometry; oblique viewing angles 30–45°	Targeted low-altitude surveys (20–50 m AGL); overlap 80–90%	Rapid regional survey followed by detailed local inspection	RTK/PPK or GCP-supported surveys
AI application	Automatic building extraction, roof classification, exposure mapping [22-24].	Rapid damage classification and change detection [12].	Semantic segmentation automated change detection and damage grading	Crack detection and engineering support; expert validation remains essential [12].	Routing optimisation, hotspot identification and resource prioritisation	Automated attribute extraction, semantic modelling and structured damage

[a] relevance for small towns with ageing low-rise buildings.

interoperable GIS platforms, and future Digital Twin environments supporting urban seismic resilience. Using commercially available UAV platforms, RTK-supported positioning, and established photogrammetric workflows, centimetre-level geospatial datasets can be produced efficiently without extensive field surveying. This illustrates an important level of technical readiness for implementing UAV-supported digital documentation of the built environment. Although the present study employed only nadir imagery, future developments may incorporate oblique imagery acquisition, AI-assisted feature extraction, and standardized digital workflows to improve post-earthquake damage assessment and evidence-based decision-making.

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REFERENCES

1. F. Nex and F. Remondino, "UAV for 3D mapping applications: A review," Appl. Geomatics **6**, 1–15 (2014). https://doi.org/10.1007/s12518-013-0120-x.
2. I. Colomina and P. Molina, "Unmanned aerial systems for photogrammetry and remote sensing: A review," ISPRS J. Photogramm. Remote Sens. **92**, 79–97 (2014). https://doi.org/10.1016/j.isprsjprs.2014.02.013.
3. Federal Emergency Management Agency (FEMA), *Building Damage Assessment Operations Manual* (FEMA, Washington, D.C., 2021).
4. Copernicus Emergency Management Service, *Rapid Mapping Service – Product Portfolio, Technical Guidelines and Product Specifications* (Copernicus EMS, 2023).
5. A. Vetrivel, M. Gerke, N. Kerle, F. Nex, and G. Vosselman, "Identification of damage in buildings based on gaps in 3D point clouds from very high resolution oblique airborne images," ISPRS J. Photogramm. Remote Sens. **105**, 61–78 (2015). https://doi.org/10.1016/j.isprsjprs.2015.03.016.
6. D. Duarte, F. Nex, N. Kerle, and G. Vosselman, "Towards a more efficient detection of earthquake-induced facade damages using oblique UAV imagery," The Int. Arch. Photogramm. Remote Sens. Spatial Inf. Sci. **XLII-2/W6**, 93–100 (2017). https://doi.org/10.5194/isprs-archives-XLII-2-W6-93-2017.
7. European Commission, *European Framework for Digital Building Logbooks*, Technical Report (Publications Office of the European Union, Luxembourg, 2024).
8. International Organization for Standardization, *ISO 19650-1:2018 — Organization and Digitization of Information about Buildings and Civil Engineering Works* (ISO, Geneva, 2018).
9. United Nations Office for Disaster Risk Reduction (UNDRR), *Global Assessment Report on Disaster Risk Reduction 2022 (GAR2022)* (UNDRR, Geneva, 2022).
10. C. Coetzee and D. Van Niekerk, "Tracking the evolution of the disaster management cycle: A general system theory approach," Jàmbá: J. Disaster Risk Stud. **4**, 1–9 (2012). http://dx.doi.org/10.4102/jamba.v4i1.54.
11. S. Gomez and H. Purdie, "UAV-based photogrammetry and geocomputing for hazards and disaster risk monitoring – A review," Geoenviron. Disasters **3**, 23 (2016), https://doi.org/10.1186/s40677-016-0060-y.
12. R. Zhang, H. Li, K. Duan, S. You, U. Liu, F. Wang, and Y. Hu, "Automatic detection of earthquake-damaged buildings by integrating oblique UAV photography and infrared thermal imaging," Remote Sens. **12**, 2621 (2020), https://doi.org/10.3390/rs12162621.
13. Bulgarian Institute for Standardization, *BDS EN 1998-1/NA — Eurocode 8: Design of Structures for Earthquake Resistance — Part 1: General Rules, Seismic Actions and Rules for Buildings — National Annex* (BDS, Sofia, 2012).
14. Agisoft, *Agisoft Metashape Professional (Version 2.2.1), Software User Manual* (Agisoft LLC, St. Petersburg, 2026).
15. T. I. Allen and D. J. Wald, "Topographic slope as a proxy for seismic site-conditions (VS30) and amplification around the globe," U.S. Geological Survey Open-File Report 2007-1357, 1–69 (2007).
16. T. I. Allen and D. J. Wald, "On the use of high-resolution topographic data as a proxy for seismic site conditions (VS30)," Bull. Seismol. Soc. Am. **99**, 935–943 (2009). https://doi.org/10.1785/0120080255.

17. Pl. Maldvanski and Ya. Stamenova, "Близкообхватната цифрова фотограметрия – източник на данни за инвестиционното проектиране," Annual of the University of Architecture, Civil Engineering and Geodesy **58**, Art. 4 (2025). DOI: 10.71167/uaceg.2025.58S104 (In Bulgarian).
18. M. Todorova, M. Kouteva-Guentcheva, and L. Pashova, "Challenges towards the implementation of Digital Building Logbooks," in Proceedings of the Scientific Conference "Knowledge, Science, Innovation, Technologies," Vol. 4, pp. 1236–1254 (2024).
19. M. Todorova, "Review of best practices for integrating digital building logs for a sustainable built", Annual of University of Architecture Civil Engineering and Geodesy, Vol. 58 (1), 81-93, (2025). DOI: 10.71167/uaceg.2025.580105 (In Bulgarian)
20. Bulgarian Civil Aviation Administration (BCAA), *Drone Information Portal and Airspace Geographical Zones*, Official CAA Guidelines (BCAA, Sofia, 2025).
21. European Union Aviation Safety Agency (EASA), *Drone Open and Specific Categories – Operational and Technical Requirements*, EASA Rules (EASA, Cologne, 2023).
22. N. M. Levine and Spencer, B. F., Jr. "Post-Earthquake Building Evaluation Using UAVs: A BIM-Based Digital Twin Framework". Sensors, **22**(3), 873.(2022). https://doi.org/10.3390/s22030873
23. D. Jia, Liu, Y., Zhang, L. "A rapid evaluation method of the seismic damage to buildings based on UAV images", Geomatica, **76**(1), 100006, (2024). https://doi.org/10.1016/j.geomat.2024.100006
24. G. Grünthal (Ed.), *European Macroseismic Scale 1998 (EMS-98)* (European Centre for Geodynamics and Seismology, Luxembourg, 1998).