**Executive summary of activities conducted during the implementation period and results obtained**

To fulfill the objectives of the project, two study areas were chosen: a rural area (comprising houses, a cemetery, roads, natural and built fences, high vegetation, etc.), which is highly topographically complex, and an urban area (comprising tall buildings, roads, natural and built fences, tall vegetation, street furniture, a water tower, etc.). Topographic-cadastral plans were made for both study areas through measurements with a total station and GNSS technology.

For the study areas, flights were conducted using three UAS systems:
(1) the DJI Phantom 4 Pro UAS system,
(2) the DJI Matrice 300 RTK system equipped with the "Share UAV PSDK 102S Pro" camera and the GeoSun GS-130X LiDAR sensor ***in addition to what was mentioned in the project implementation plan*** and
(3) the DJI Phantom 4 RTK UAS system.

The DJI Phantom 4 Pro UAS system was modified by installing the TeoKIT AGNSS L2 conversion kit, transforming it into a PPK UAS system.

One hundred ground control points were established and evenly distributed across the rural study area, and 43 were established for the urban study area. All GCPs were measured with a total station, either as measured points from survey points or as actual survey points (both in rural and urban areas), and also using RTK technology with the Emlid Reach RS2 GNSS receiver. Differences between coordinates determined with the total station and RTK technology did not exceed 2 cm. Prior to UAS flights, the ground control points were marked using coded and un-coded targets to ensure their stability during flights. Many points were also painted with a pattern to ensure visibility during flights.

UAS images were processed using different scenarios with RealityCapture and 3DF Zephyr software, employing RTK and PPK positioning technology and ***additionally using indirect georeferencing*** with varying numbers of ground control points while keeping the number of checkpoints constant (64 for the rural area and 33 for the urban area). Planimetric errors for flights with the DJI Phantom 4 system were 2-3 cm for oblique flights and 3 cm for nadiral flights, except for nadiral flight scenarios without GCPs, which resulted in a 1 dm error. Vertical errors for oblique flights were approximately 2-3 cm, while total errors were around 3-4 cm. For flights with the SHARE camera, total errors were approximately 4-5 cm at 60 m altitude for scenarios without GCPs and 5-6 cm at 100 m altitude. The introduction of 3 GCPs improved errors by approximately 1 cm.

UAS point clouds and orthophoto plans for both rural and urban study areas were generated automatically using RealityCapture and 3DF Zephyr software functions. UAS point clouds were classified into "ground" and "non-ground" points using the Cloth Simulation Filter (CSF) algorithm implemented as a plug-in in the open-source CloudCompare software. Using OPALS software developed by the Technical University of Vienna and command lines, Digital Terrain Models (DTMs) and Digital Surface Models (DSMs) were created in raster format. Standard deviations were calculated for DTM and DSM accuracy evaluations using ArcGIS software based on ground measured points and ground measured points and building roof points, respectively. For the rural area, the median absolute deviation ranged from 1.3 cm to 2.9 cm, while for the urban area, the standard deviation ranged from 3.0 cm to 4.8 cm for DTM. DSM accuracy was lower than DTM accuracy, with errors ranging from 4 cm to 6.5 cm for the rural area and from 17 cm to 28 cm for the urban area.

The rural study area was scanned using the Trimble MX9 mobile terrestrial scanning system ***(in addition to the project implementation plan)***, resulting in a point cloud of 192,722,817 points. Both rural and urban study areas were scanned using the GeoSun GS-130X LiDAR sensor mounted on the DJI Matrice 300 RTK UAS system at two different heights, 60 m and 100 m, resulting in point clouds in the STEREO-70 coordinate system for (X,Y) coordinates and the Black Sea-1975 system for altitudes, with two scenarios: trajectory compensation using PPK and RTK techniques, with PPK offering more precise results than RTK. Additionally, two flights were conducted in the urban area, one with the BLV 6100 camera and one with the Zenmuse camera (in addition to the project implementation plan), for nadiral image acquisition. UAS point clouds for scenarios with the smallest residual errors, without using ground control points (GCPs) or using a minimal number of ground control points for nadiral flights, were evaluated for accuracy and completeness through comparative analysis with data obtained through mobile laser scanning technology (MLS) (roads and parking lots) for the rural study area and with 100 points measured with a total station on building roofs and on the ground for the urban study area. For the rural area, the median absolute deviation ranged from 2.2 cm to 3.0 cm, while for the urban area, the standard deviation ranged from 2.8 cm to 4.6 cm.

Cadastral boundaries, including natural and artificial fences (rural area) and roads, were manually digitized using AutoCAD Map 3D software based on orthophoto plans. Standard deviations of distances between manually extracted polylines and measurements made with the total station were obtained, along with completeness, using ArcGIS Pro software. For rural roads, the standard deviation was approximately 17 cm, with digitization completeness ranging from 90-95%, while for fences, the standard deviation was approximately 10 cm, with digitization completeness ranging from 20-45% depending on the flight. In the urban area, roads were digitized with an accuracy of approximately 19 cm, with completeness at 55%.

To evaluate the accuracy of LiDAR-UAS point clouds, Hausdorff distances between each GCP and the mesh surface created from the LiDAR cloud were calculated, resulting in standard deviations, along with manual measurement of coordinates for a number of 33 paint-marked points in the rural area and 29 points in the urban area. A standard deviation of approximately 2 cm was obtained for the rural area at 60 m altitude and approximately 2.8 cm at 100 m altitude. In the urban area, errors were higher, reaching 4 cm at 60 m and 5 cm at 100 m altitude.

***A new method*** for classifying ground points was developed ***(in addition to the project implementation plan)***, using a hierarhic robust filtering algorithm and applying an 80% slope condition for the filtering result using the volume-based algorithm. The proposed method accurately represents artificial structures and abrupt slope changes, improving the accuracy of Digital Terrain Models (DTMs) by 40% for a flight height of 60 m and by 28% for a flight height of 100 m using 985 check points.

For measuring topographic details not visible in UAS images, two different systems for close-range photogrammetry using GNSS technology were proposed and tested. Both systems are based on the Sony ZV-1 digital camera. The first system (S1) integrates an Emlid Reach RS2 RTK GNSS receiver mounted on a pole, while the second (S2) features a manually made PPK GNSS device consisting of an Emlid Reach M2 module, a cable for power supply from an external battery, an adapter for the camera flash, and a multi-band helical GNSS antenna. The second device was developed ***in addition to project activities***. Root mean square errors along the three axes were approximately 2 cm without using GCPs, representing high accuracy for ground measurements.

The activities carried out during the implementation period have resulted in the acquisition of comprehensive datasets and valuable insights into the topography of the study areas. These datasets serve as a solid foundation for further analysis and decision-making processes. The use of various technologies, including UAS, GNSS, LiDAR-UAS, and terrestrial laser scanning, has enabled the collection of detailed and accurate spatial information in both urban and rural environments.

By combining data from multiple sources, such as aerial imagery, point clouds, and ground control points, we have achieved a high level of precision in mapping and modeling terrain features.

This precision is essential for various applications, including urban planning, land management, environmental monitoring and infrastructure development.

Furthermore, the integration of different methodologies, such as RTK and PPK GNSS positioning, as well as the development of novel approaches for ground point classification and point cloud alignment, has enhanced the accuracy and reliability of our results. These methodological advancements contribute to the advancement of geospatial science and technology.

Overall, the datasets generated through these activities provide valuable information for stakeholders and decision-makers involved in urban and rural development projects. They enable informed decision-making processes and support the sustainable management of natural resources and built environments.