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A Technical-Thematic Civil Protection Exercise in Italy: UAS Fleets-Based Activities Supporting Emergency Response in Seismic Scenarios

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Abstract: In October 2023, during the Italian Civil Protection Week, in Eastern Lombardy (Italy) a large technical-thematic seismic exercise called "EXE.Lomb.Est 2023" was organized, with the goal of testing the response of the Regional Civil Protection system for post-earthquake damage assessment activities. Within this context, the use of an unmanned aerial system (UAS), in particular the deployment of multi-rotors UAS teams, has been tested as support for the rapid mapping of a large area involving the simultaneous participation of different Italian institutions with UAS units. Coordinated flight planning design, safety issues, coordination and communication procedures, data management and delivery of the results are some of the main aspects investigated and presented in this work.

Keywords: civil protection; multi-rotor unmanned aerial system (UAS); rapid mapping; coordinated flight strategy; tactical and strategical risk mitigations

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1. Introduction

Natural disasters, such as earthquakes, floods and wildfires, are likely to bring extensive damage, even over large areas, causing human, economic, material and environmental losses. Rescue activities are organized depending on the morphology and the extension of the affected area and on the type and severity of the calamity ([1]). Nevertheless, the implementation of such activities is hindered by the lack of information regarding the most affected territories and the actual conditions of infrastructures and transportation networks. To deal with time and to decrease the number of casualties and economic losses, an effective network-based disaster management system (DMS; [2]) is needed, within which crucial roles are played by the distribution and collection of information, the prioritization of rescue and technical intervention, the disaster area monitoring as well as continuous communication with the coordination centers.

Aerial remote sensing is becoming an important resource for DMS authorities to deal with some of these issues and to increase the understanding of the territory in the aftermath of a large-scale disaster ([3]), when it is crucial to have a quick and updated appraisal of the situation (i.e., extension of impacted area, limitations for the rescue operations).

Within this context, unmanned aircraft systems (UASs) are being progressively tested to support civil protection in the post-disaster activities related to humanitarian relief, damage mapping ([4–12]) and, in general, the mitigation of disaster impacts ([13,14]). Landslides monitoring ([15]), logistic or search and rescue operations ([16–20]), ground network communications restoration ([21–23]) and damage assessment (also assisted by AI technologies) for the usability evaluation of structures [24–29]) are some of the specific fields of application.

Although the majority of the above-mentioned applications involve the use of single UAS (sometimes custom-made for research goals), the employment of multiple UASs (fleets) supporting emergency management is recognized as a powerful solution by different works and on-site applications ([21,30–32]).

UASs have many advantages in disasters management ([3,33]): low operating and acquisition cost, limited exposition of pilots to dangerous areas, rapid placement and reaction time, scalable intervention and access to otherwise inaccessible locations. In addition, they can be equipped with a large variety of sensors, from LiDARs to sensors to measure smoke composition, wind speed, to name a few.

Nevertheless, the use of UASs, especially if operated simultaneously, involves a series of technical and operational challenges, still deserving investigation and testing, also keeping in mind the compliance with the regulatory restrictions, which is an additional not-negligible aspect concerning operations with drones. In particular, according to the current European regulation ([34,35]), when an "emergency response effort is ongoing", UAS operators are allowed to fly only under specific permission issued by the "responsible emergency response services". Some of the crucial aspects are in fact the interaction with the national aviation authorities in the view of a standardized activation procedure for UAS teams and the safe and coordinated management of the shared airspace (considering the likely presence of manned vehicles).

Data collection, coordination and communication, safety issues, interaction within the emergency management system and use of aerial space are, amongst others, the transversal main challenges/objectives addressed in the present paper in the context of the technical exercise named "EXE.Lomb.Est 2023", focused on the use of drones for civil protection activities that took place on 9–14 October 2023.

Within the perspective of a coordinated disaster response, the Italian Civil Protection system takes advantage of the joint effort of its different components: the UAS teams of the Competence Centres are among the resources that can be deployed to support the national fire brigades (CNVF), which are in charge of the overall coordination of urgent technical response. The Competence Centres of the Italian Civil Protection Department constitutes a network providing services, information, data and technical-scientific contributions in specific areas. Such functional center networks include state governments, agencies, research institutes, universities and basin authorities. All the teams operating under the coordination of the CNVF but not belonging to fire brigades are called "external bodies".

The challenge was not only technical: the idea was to establish and test a comprehensive standardized methodology, intended as a guideline applicable on a large scale as it combines technical, operational and planning aspects together. For the first time, standard protocols for UAS operations and activation were defined, tested and supported for the occasion by the Italian UAS U-space service provider (D-flight, [36]), in agreement with the national aviation authorities (ENAC and ENAV) and the national fire brigades.

A second part of the exercise focused on the technical aspects. First of all, with regard to data collection, the surveys carried out by the different teams responsible for mapping the assigned parts of the overall are, must be comparable; therefore, they were conducted on the basis of common protocols. Finally, the data collected requires rapid processing to be made available to the coordination center within times compatible with the needs of organizing rescue operations. The initial joint activities were then followed by individual specific assignments still related to drone assessments in an emergency context but will not be discussed within this paper.

The exercise scenario was based on the simulation of the occurrence of an earthquake of Mw = 6.0, which struck the territory of Mantua county in northern Italy (Figure 1 and more details in Section 3): the Civil Protection operations room of the Lombardy Region was activated, and the response activities were coordinated by the CNVF. Regarding UAS support activities to CNVF, the following Competence Centres of the Italian Civil Protection Department took part in the exercise joint activities: EUCENTRE Foundation, CIMA Research Foundation, the Civil Protection Centre of the University of Firenze (UNIFI), the National Research Council (CNR), the National Institute of Geophysics and Volcanology (INGV) and the regional Agencies for Environment of Lombardia, Valle d'Aosta and Calabria (ARPA Lombardia, ARPA VDA and ARPACAL).

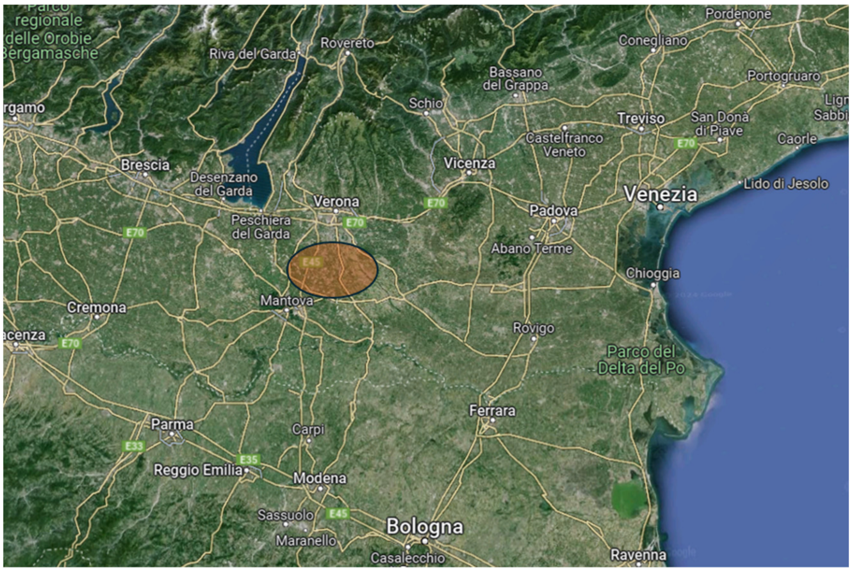

Figure 1. Emergency exercise location in the Mantua province territory (Source: Google Maps).

In this first experimentation of the system, three "macro-areas" of activity were conducted, focusing on aspects deemed to be of primary interest:

1. The coordination of air operations, which involved the CNVF and the UAS networks through the establishment of a main coordination center of overall air operations (CCOA), a second one close to the affected area as a liaison between the former and the on-site response (both managed by the CNVF) and a UAS coordination center for the technical activities of UAS networks (UAS CCT), operating at the local level in close cooperation with the other two. The focus of the exercise was to test the chain for requesting activities, the procedures for activating the no-fly zone (NFZ), as well as the activation and management of the UAS activities of the so-called "external bodies" (i.e., not belonging to the CNVF);
2. A joint technical activity, which saw the participation of the involved Competence Centers (EUCENTRE, CIMA, UNIFI, CNR, INGV, ARPA Lombardia, ARPA VDA, ARPACAL). Regarding this activity, we focused more on the activation aspects, on the procedural aspects of data acquisition and interferences management and on the aspects of conducting a joint activity by teams belonging to different institutions;
3. Individual technical activities, which saw the participation of the EUCENTRE teams in collaboration with the CNVF, the Municipality of Monza for the survey of some structures and the municipalities of Quistello, Monza and Milan for surveillance/public safety activities. As mentioned above, these activities will not be discussed in detail within this paper.

2. The Air Operations Coordination Center

In order to coordinate aerial activities, including those operated by drones, a coordination model was defined and tested, inspired on the lesson learned during the 2022 flood emergency experience in Emilia Romagna (Italy).

The coordination center of overall air operations (CCOA) is established as point of reference of all flights, for the coordination of manned and unmanned operations, the operation authorization, the airspace reservation (i.e., no-fly zones, NOTAM, etc.), communications and feedback on the beginning and conclusion of each operation, etc. The CCOA, chaired and managed by the CNVF, ideally hosts representatives of the Air Force and of the Department of National Civil Protection and representatives of the Regional Civil Protection.

The center was established at the Curno headquarters of the Lombardy Region, ordinarily managed by the CNVF for forest fire fighting activities; Air Force and National Civil Protection Department officers were only simulated for the exercise, while Lombardy Civil Protection function was delegated to the CNVF as regional coordinator of the Curno center.

A branch office of the CCOA was established in Mantua and coordinated by the local CNVF unit, responsible for managing the manned and unmanned flights of the CNVF fleet, as well as authorizing the external institutions' unmanned flights, through the technical coordination center of the external UAS networks (UAS CCT), also based in Mantua, which managed operators and teams for activities assigned to the UAS networks by the CCOA.

The UAS networks CCT collected requests relating to the technical activities assigned by the CCOA, monitored the progress of the activities themselves, supported the field teams (including monitoring the D-flight portal), and managed the delivery of the requested products to the relevant stakeholders.

Figure 2 illustrates the communication diagram flow.

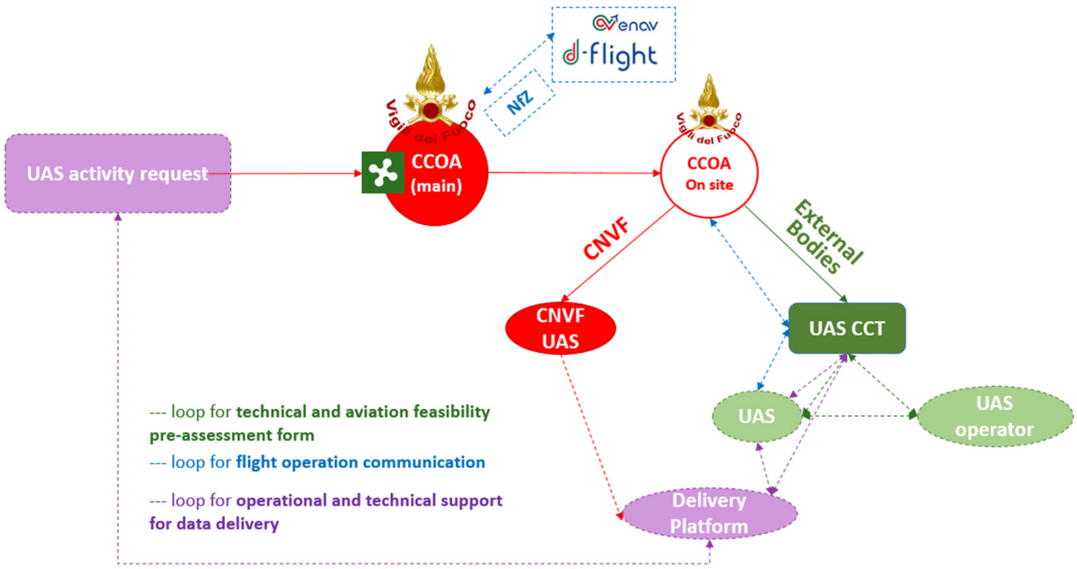

Figure 2. Communication diagram flow.

2.1. *Procedure for the Establishment of the No Fly Zone (NFZ)*

To smooth the process while still maintaining an appropriate level of safety, minimal U-Space services (such as those of network remote identification, traffic information and dynamic geo-awareness) have been put in place for the situation awareness necessary to increase the safety of air operations even if conducted in an emergency context.

An ENAV/D-flight–CNVF agreement established a test procedure that allowed the real-time activation of ad hoc NFZs immediately active on the D-flight portal ([36]) to protect the operation area, within which only authorized manned and unmanned traffic below 120 m above ground level (AGL) can fly. Authorization was managed by the CCOA.

In summary, the established protocol consisted of what follows:

- The CCOA, at least 15 min in advance, requires for D-flight the creation of the NFZ (providing center coordinates, radius and vertical limit if less than 120 m AGL);
- The D-flight Task Force in charge provides the creation of the NFZ;
- The CCOA requires deletion of the NFZ upon the completion of activities.

2.2. Management of the Tasks Assigned to the "External UAS Fleet"

The operation procedures of the management of tasks assigned to the "external UAS fleet" (i.e., teams not belonging to CNVF) have been established in agreement with the CNVF according to a basic scheme in which UAS CCT collected information from each single operator and communicated it to the CCOA. The defined standard scheme is as follows:

- Every evening, the arrangements for the crew consistency for the following day are sent by email with an established form. Every morning, only variations are communicated (telephone and email);
- Every evening, daily activity reports from each field team are sent by email according to the established format;
- Once an activity has been assigned, each team (or the responsible team in the case of joint activities) carries out a rapid analysis of the concept of operation (CONOPS) using the established form "Fast_Conops_Assessment" and confirms the feasibility to the UAS CCT, possibly iterating if needed;
- Once the activity has been authorized and the relevant time window has been assigned by CCOA, each team communicates the start and end of the flight operations to the UAS CCT. If NFZ is foreseen, each team checks if it has been activated before starting any flight operations.

A radio was assigned to each team for communications with the UAS CCT, including those related to simulated and/or real emergencies (the so-called "zero-code" alerts). In the case of joint activities, each joint activity had, in addition, its own dedicated radio network for internal communications.

3. The Joint Technical Activity: Emergency UAS-Based Aerial Photogrammetry

The joint technical activity consisted of the so-called "emergency aerial photogrammetry", i.e., the deployment of multi-rotors UAS teams to map a medium–large area affected by the seismic event. As reported in more detail in Mandirola et al., 2021 ([32]), this joint activity has two main general goals with different levels of time constraints and result accuracy demands. The first goal in the immediate response phase is to provide essential and timely information to the authorities in charge of disaster response activities (e.g., the National Civil Protection). In this phase of rapid mapping, in order to survey and transfer the preliminary results in the shortest possible time, a high level of detail and spatial resolution (ground sampling distance—GSD) is not really necessary. The information delivered could be in the form of low-resolution (e.g., 10 cm/px) orthophoto able to provide a near real-time picture of the affected area, allowing a fast assessment (e.g., identification the access points, prioritization of the field inspections and post-event reconnaissance activities). In a second phase, when the timeliness of the delivery is less demanding, or upon specific requests, additional data can be acquired (e.g., flights with oblique camera, lower flight altitude/GSD, larger lateral overlap), or more accurate products can be provided (e.g., 3D point clouds, 3D models, digital elevation models or orthophoto obtained with higher accuracy parameters with respect to previous results). These data can offer the metrics base for advanced activities, such as the assessment of debris volume ([32]) or numerical modeling of the disaster impacts (e.g., impact on the structural performance of infrastructure [25]).

The application described in what follows has been focused especially on the rapid mapping phase.

3.1. Test Site Description and Concept of Operations

The test site selected for the in situ application of rapid mapping, located between the municipalities of San Giorgio Bigarello and Castel Belforte (in province of Mantua in Italy—see Figure 3), is a large rectangular area (of about 450 ha) with a flat morphology and the possibility for the pilots to walk across in order to ensure that the VLOS (visual-line-of-sight) conditions are met (at the time of application, this is still a mandatory requirement). The total area has been mapped operating five UAS teams flying simultaneously on a sub-area of about 100 ha each, with a relative overlap of about 10–15% of the single sub-areas (see Figure 3). These sub-areas have been established based on the capabilities of each UAS and the input flight planning parameters reported in Table 1, considering that each team had to guarantee approximately one hour of continuous flight.

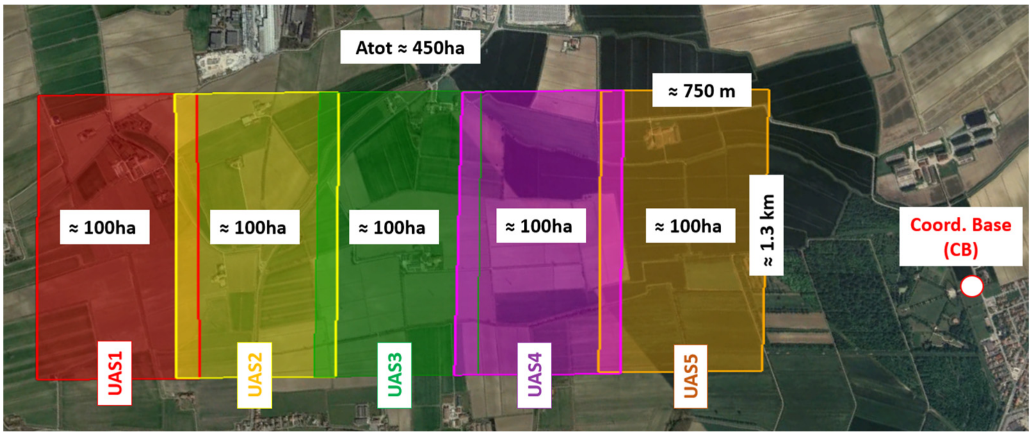

Figure 3. Target area selected for the rapid mapping activity, subdivided in five sub-areas. Source: Google Earth Pro.

Table 1. Summary of the flight planning parameters set during EXE1 and EXE2.

	Flight Parameter
Flight height	115–120 m AGL
Frontal and lateral image overlap	80% F–65–70% L
Maximum velocity [1]	7 m/s–9.7 m/s
Camera orientation	Nadiral

[1] Set according to the UAS camera performance and the weather and illumination local conditions.

On the same area, the survey exercise has been repeated twice, varying the typology of employed multi-rotors: UAS with maximum take-off mass (MTOM) < 2 kg (EXE 1) and UAS with 2 kg < MTOM < 25 kg (EXE 2).

The location and flight parameters have been selected in order to comply with safety requirements. At the time of the exercises, according to the D-flight portal, in the area of interest there were no particular restrictions or authorization requirements, and the operations were allowed up to the maximum height of 120 m AGL.

The overall on-site activity took place in two days, the 10th and 11th of October 2023, and involved a total of 35 participants from the Competence Centres of the Italian Civil Protection Department (listed in Section 1) and 11 multi-rotors (Figure 4). The weather conditions during all the days were generally favorable (good visibility and temperature around 20 °C).

Figure 4. Emergency aerial photogrammetry activity: team pictures.

The mobile units of the National Research Council (CNR) and the EUCENTRE Foundation, located in a parking close to the area of survey and equipped with high-performance desktop workstations (e.g.,: EUCENTRE workstation: Intel(R) Core(TM) i7-9800X, CPU 3.8 GHz (Santa Clara, CA, USA), 32 GB RAM with Nvidia GeForce GTX 1080), have been employed as the on-site coordination base (CB, see Figures 3 and 5) for operations management, support battery charging (using external power generators), data processing and connection with the UAS CCT/CCOA.

Figure 5. Emergency aerial photogrammetry activity: in situ coordination base.

Given the surrounding environment (mostly agricultural non-urban area), for the purpose of the present exercise, particular safety precautions have been taken in order to keep the risk of the operation basically equivalent to the Italian standard scenarios (IT-STSs—specific category), according to the current regulation ([34,35,37,38]). Such arrangements are summarized in Table 2.

Table 2. Emergency aerial photogrammetry activity: summary of the main risk mitigations applied.

Strategic Risk Mitigations
- Activation of a dedicated NFZ on D-flight portal (red in Figure 6, top left), authorized by the ENAC;
- Start of the flight operations only after authorization from the UAS CCT/CCOA to the CB;
- UASs equipped with real-time remote identification (Pollicino tracker, [39]—Figure 6, top right and bottom left);
- Common communication phraseology;
- Coordinated simultaneous flight strategy (schematically reported in Figure 7);
- Pre-mission on-site briefing (Figure 6, bottom right) to check the main aspects (e.g., team ID, planning parameters, radio connection, team equipment, . . .);
- Trained and qualified person with dedicated role at the CB.
Tactical risk mitigations
- Constant communication via radio (two different frequencies) and mobile phone: UAS CCT-CB and CB-UAS teams;
- Real-time monitoring of the UAS tracker (green in Figure 6, top left) and air manned traffic services at the CB (information displayed on a big screen installed on operational vehicle at the CB) and at the UAS CCT;
- Flight UAS control mode: automatic and manual operation (the pilot is always able to take control of the UAS);
- UAS pilot with at least IT-STS license + payload-trained assistant;
- UAS team of three-quarters trained persons: pilot + payload assistant + visual observer/radio assistant/dataset analyst;
- All the flights planned carried out in VLOS condition and in compliance with daytime;
- UAS termination flight system (at least integrated in the flight controller, like CSC command * of DJI drones).

* Combination stick command (CSC), which allows an immediate stop of the drone motors.

Figure 6. Some risk mitigations applied during UAS joint activity: NFZ visualized in D-flight with the drone trajectories in green (**top left**—images courtesy of Topview), drone tracker (**top right** and **bottom left**) and on-site meeting with all the UAS teams (**bottom right**).

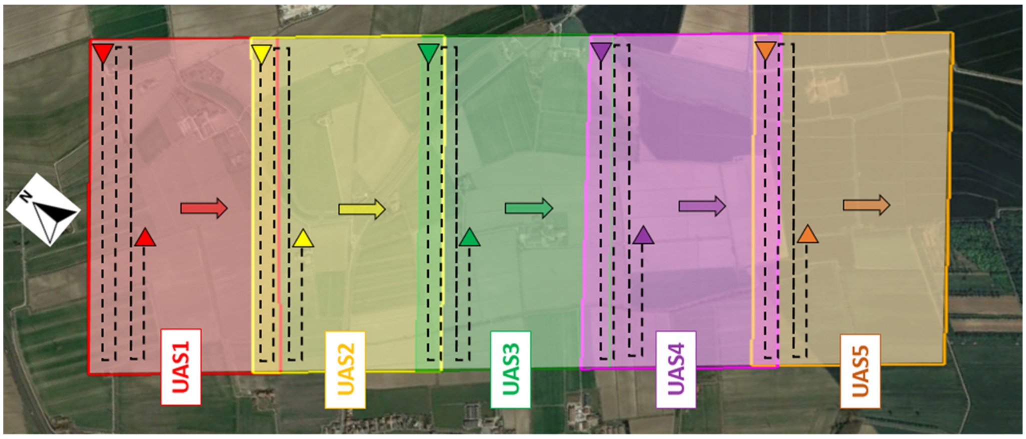

Figure 7. Emergency aerial photogrammetry activity: qualitative sketch of the coordinated simultaneous flight strategy adopted.

The following strategy has been adopted, given the presence of simultaneous flights, in order to minimize the risk of collision between adjacent UASs (in addition to the parameters reported in Table 1):

- Sub-area of survey clearly refined by a kml file imported in the flight planning software used by each UAS team when possible;
- Automatic waypoints flight trajectories almost parallel to the shortest dimension of the entire area, always proceeding from northwest to southeast (as schematically reported in Figure 7);
- Take-off, landing and return-to-home (RTH) points within the boundary of each assigned sub-area;
- Different RTH flight height: 120 m for sub-areas 1, 3 and 5 (red, green and orange in Figure 3) and 90 m for sub-areas 2 and 4 (yellow and purple in Figure 3);
- Low battery level warning set to 30%.

Once each team reached a suitable position in the assigned sub-area, the operative procedure adopted between the UAS teams and the CB (constant communication ensured mostly via radio) was based on the following main steps:

1. Check of the radio signal;
2. Transmission of the take-off position of each team (via WhatsApp);
3. Communication of the "ready-to-take off" status by each team;
4. Once feedback #3 has been received from each team and after flight authorization from the UAS CCT/CCOA, the CB proceed to order the "GO to take-off" firstly to Team5 (orange area in Figure 3);
5. Only after Team5 has been informed about the start of its automatic waypoint mission, the CB proceeds to order the "GO" to Team4 (purple area in Figure 3) and so on until Team1. In this way, a proper spatial horizontal buffer between the adjacent drones has been guaranteed (considering the limited extension of the overlap areas with respect to the whole dimension of the sub-areas). If a TeamX faces issues causing unexpected long delays during this initial phase, in order not to stop all the other missions, the CB proceeds to activate the adjacent TeamX-1 (according to the level of progression of Team X-1 missions, as for safety reasons TeamX would need to wait until the end of Team X-1's entire missions before starting);
6. During all the flight operations, every significant piece of information needs to be promptly shared: landing/take-offs and battery swaps, along with any eventual issue causing unexpected delays in the operations (e.g., emergency situations).

A fast quality check on the dataset acquired (i.e., image quality control, data completeness and a preliminary photo alignment in lowest accuracy) has been performed right after each battery swap by a dedicated trained member of each UAS team (using a standard-performance laptop). Moreover, the images were organized in folders according to shared label conventions in order to optimize the elaboration phase at the CB.

3.2. Main Preliminary Outcomes

The total mission time from the first take-off to landing of the last mission (including all the battery swaps as well as all unexpected issues) was around 2.5 h for EXE 1 and 3 h for EXE 2, with an effective flight mapping time of about 1 h and 5–10 min (average between all the teams). As reported in Tables 3 and 4, a total of about 4300 and 5200 images (JPEG format) were collected for EXE 1 and EXE 2, respectively.

Table 3. EXE 1: summary of the UAS teams involved, target area and dataset collected.

ID Team	UAS	Sub-Area (Figure 3)	Dataset Collected
#1—INGV Pisa	DJI Phantom 4 Pro	Red	755 img (5.25 Gb)
#2—CNR	DJI Phantom 4 Pro V2	Yellow	838 img (6.85 Gb)
#3—ARPACAL	DJI Mavic 2 EA	Green	895 img (14.5 Gb) *
#4—CIMA	DJI Mavic 2 E	Purple	955 img (7.40 Gb)
#5—ARPA VDA	DJI Phantom 4 Pro	Orange	874 img (7.10 Gb)
		Tot: ~450 ha (10–15% overlap)	4317 img (41.1 Gb)

* Image resolution wrongly set at 48 Mpx wrt max 20 Mpx of the other teams.

Table 4. EXE 2: summary of the UAS teams involved, target area and dataset collected.

ID Team	UAS	Sub-Area (Figure 3)	Dataset Collected
#1—INGV Roma	DJI Matrice 300 (L1 RGB)	Red	753 img (6.11 Gb)
#2—CNR	DJI Matrice 300 (L1 RGB)	Yellow	811 img (6.69 Gb)
#3—ARPA Lombardia	DJI Matrice 210 V2 (X5s)	Green	1458 img (10.1 Gb)
#4—CIMA	DJI Matrice 210 V2 (X5s)	Purple	1203 img (8.11 Gb)
#5—UNIFI	Saturn M2	Orange	974 img (8.42 Gb)
		Tot: ~450 ha (10–15% overlap)	5199 img (39.4 Gb)

The first approach investigated was to process the images of each team separately (right after their arrival at the CB), using medium/high parameter settings, exportable in low resolution for a fast first delivery. This approach has been tested in order to have the possibility, upon specific request, to export a more accurate product without repeating the elaboration (e.g., the full resolution of the orthophotos has been of 2–4 cm/px for a tiff file dimension of about 3 Gb each).This phase, managed by the CNR mobile unit team, was carried out using the software DJI Terra version 3.9.3. The overall elaboration time was about 1 h and 50 min for EXE1 and 2 h and 20 min for EXE2. In this phase, georeferencing was undertaken by means of the GNSS installed on the UAS (without using GCPs on the field or RTK). The single ortophotos, exported in tiff format with a low resolution of 10 cm/px (maximum size of 135 Mb each), were the first product delivered. All the main products were shared with the UAS CCT through a dedicated folder activated on a web-based file repository of the CNVF.

Following other recent field experiences of some of the authors ([32]), a parallel low-resolution elaboration was carried out (always at the CB) using the batch process implemented in Agisoft Metashape version 2.0.3.16915 ([40]), installed in the EUCENTRE workstation. The entire dataset collected was processed in a single chunk with the following workflow: photo alignment (low resolution), depth maps (lowest resolution with aggressive filter), DEM and ortophoto. The total elaboration time was about 1 h and 30 min both for EXE1 and EXE 2. The orthophoto of the whole area (with a resolution of 10 cm/px) exported in tiff format (with JPEG compression) had a size of about 650 Mb, while the kml file (importable into Google Earth Pro for a fast comparison with the pre-event situation) had a size of approximately 315 Mb.

As anticipated, the information that an orthophoto makes available is suitable within an immediate emergency response scenario since it allows for a fast assessment of the general situation, the extension of the affected area and a fast check of the accessibility (Figures 8 and 9).

Figure 8. Ortophoto of the whole area obtained with Agisoft Metashape: simulation of a fast investigation of the overall situation of portions of the affected area surveyed during EXE 1.

As checked later at the CNR workstation, despite the different approach to ortophoto generation, DJI Terra seems to guarantee a significant reduction in computational time with respect to Agisoft when keeping similar elaboration parameters. Additional investigations involving a test of performance and accuracy reconstruction of other software (e.g., Pix4DReact v1.4.3) could be part of a future development of the present work.

The possibility to repeat basically the same task exercise twice in the same location with different UASs and team members allowed a deeper investigation of the effectiveness of the proposed rapid mapping strategy enriched by the exchange of experiences among the different experts in the field. In particular, the importance of a common language as simple as possible between the coordination base (CB) and each team, the need for feedback from each team to the main instruction provided by the CB and an additional (if available) backup internal radio communication between teams surveying adjacent areas (for guaranteeing urgent safety communication) have been the main lessons learned during EXE1 and then incorporated within EXE2.

After the activities of rapid mapping (EXE1 and EXE2), the main goal of the overall exercise, in the remaining part of the second in situ day, the request for additional specific surveys of selected portions of the 450 ha was simulated (EXE3). The same operative procedures described for EXE1 and EXE2 were followed. The details of the UAS teams' equipment, the single task assignment and raw dataset collected are summarized in Table 5 and Figure 10. The total mission time from the start of the meeting with all the UAS teams at the CB to the landing of the last mission (including all the battery swaps as well as all unexpected issues) was around 1.5 h.

Figure 9. Ortophoto of the entire area obtained with Agisoft Metashape: simulation of a fast investigation of the overall situation of portions of the affected area surveyed during EXE 2.

Table 5. EXE 3: summary of the UAS teams involved, task assignment and dataset collected.

ID Team	UAS	Input (rif. Figure 10)	Product Required	Dataset Size
#1—INGV Roma	DJI Matrice 300	Sub-area red ~20 ha 100 m AGL—6 m/s 50%L–80%F	Point Cloud (Lidar—380 p/mq) +RGB	3.84 Gb
#2—CNR	DJI Matrice 300	Sub-area yellow ~20 ha 80 m AGL—6 m/s 50%L–80%F	Point Cloud (Lidar—380 p/mq) +RGB	8.35 Gb
#3—ARPA Lombardia	DJI Matrice 210 V2	Sub-area green ~2 ha 60 m AGL—grid + 45° tilt 70%L–70%F	3D building reconstruction (RGB): Point Cloud + Model	1.56 Gb
#4—ARPA VDA	DJI Matrice 300	Sub-area purple ~25 ha 80 m AGL—6 m/s 50%L–80%F	Point Cloud (Lidar—380 p/mq) +RGB	8.49 Gb
#5—UNIFI	Saturn M2	Sub-area orange ~20 ha 70 m AGL—6 m/s 50%L–80%F	Point Cloud (Lidar > 300 p/mq)	5.43 Gb

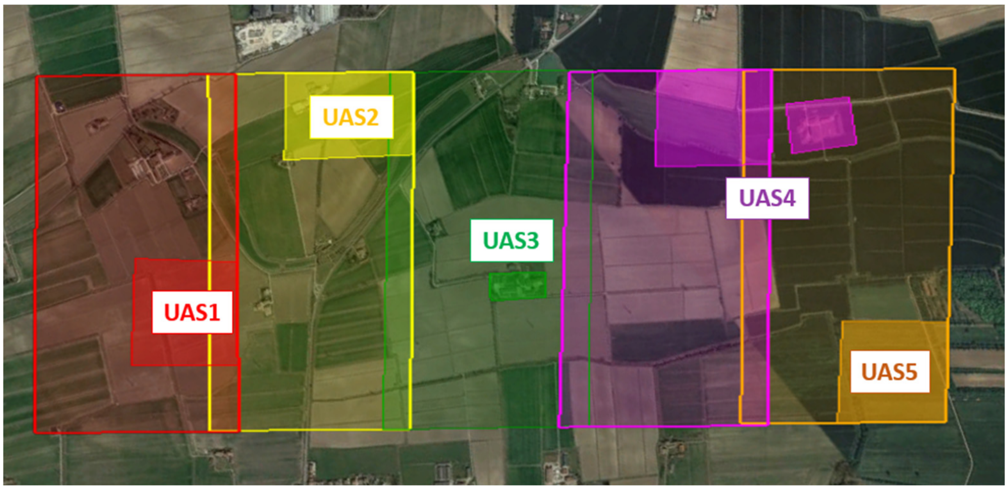

Figure 10. Selected sub-areas assigned to each UAS teams during EXE3. Source: Google Earth Pro.

Figure 11 shows some views of the 3D model reconstruction of the buildings surveyed by Team 3 in EXE3 during which a total of 240 images were collected. This elaboration, carried out by EUCENTRE using Agisoft Metashape (version 2.0.3.16915), took about 25 min (the elaboration workflow consisted of photo alignment (high resolution), depth maps and dense point cloud (medium resolution with aggressive filter), 3D model). Another product in the form of a point cloud, which may be used, for example, for specific investigation of the impact on the vegetation present in the area, obtained during EXE3, is reported in Figure 12 as a result of the survey carried out by Team 5. The processing, the centimeter geo-referencing and the classification of the point cloud took about 18 min. The coloring of the cloud took an additional 25 min of processing time.

Figure 11. Some views of the 3D model reconstruction of the buildings surveyed by Team 3 in EXE3.

Figure 12. Point cloud (about 162 mln of points) obtained from the survey of Team 5 during EXE3.

4. Lessons Learned and Discussion

The conduct of the exercise is analyzed for the two macro-areas of experimentation (activation management and emergency aerophotogrammetry) in terms of strengths, weaknesses, opportunities and threats.

One of the primary focuses of the exercise was to test the chain for the request of support, the procedures for the activation of the no-fly zone (NFZ) as well as the activation and management of the activities of the so-called "external bodies" (i.e., not belonging to the national fire brigades—CNVF).

The basic strength was the coordination system chain itself, which allowed an effective liaison between the aspects of activation and management/coordination of the operations conducted by the "external bodies".

The establishment of a joint operational headquarters shared by the local coordination center of overall air operations (Mantua) and the technical coordination center of the external UAS Networks (UAS CCT) was a crucial aspect that fostered the necessary interaction and the optimal real-time exchange of information, avoiding any otherwise physiological delay in the operations. It helped to strength the synergy between the teams (CNVF and UAS CCT networks), which were able to jointly optimize the procedures in compliance with their respective needs, including formal ones. The exercise gave also the opportunity for discussing procedural aspects with the national aviation authorities (ENAC/ENAV/D-flight), opening a dialogue which is essential to keep active and operational.

Given that the procedure was established for the first time on an experimental basis, it is certainly possible to optimize aspects above all in the communication flows and in the forms of the exchange of information.

Regarding the conduct of joint technical activities, we focused more on the activation aspects, on the procedures of data acquisition and interference management and on the aspects of conducting a joint activity by teams belonging to different institutions.

Common procedures and definition of parameters in data acquisition led to a consistent and effective dataset as requested for multicrew operations. A unique data processing environment could provide operative outcomes as hi-res ortho-images and 3D models. Other key aspects touched upon during the exercise, although not as a priority, were the feasibility assessment of the required operations and the delivery of the final products.

An excellent synergy among the different teams developed in terms of cooperation between institutions, common language and approach to problem solving. Each team understood the tasks assigned and, therefore, aware of operating within a more complex system, operated accordingly to guarantee the necessary safety conditions and to achieve the results within a common plan. The assignment of tasks, which involved the definition of a coordinator for each transversal activity (e.g., radio communication, data processing, etc.) proved useful and functional for the conduct of the assigned activities. Team building, in this sense, is also important to make operational future real deployments.

Repeating the same assignment with different strategies allowed for the evaluation of the effectiveness of the different approaches in relation to the operational context and fostered the exchange of experiences among the different experts in the field.

Great attention was paid to the safety of operations, often by means of redundancy strategies; however, from the safety point of view, the interference with manned flights without transponders is a highly critical element to pay attention to since the no-fly zone (NFZ) on the D-flight portal is generally checked only by UAS operators.

Some critical issues and some aspects that require further development and experimentation were also highlighted, mainly regarding the operation self-assessment tool and the final delivery of products to the stakeholder, which is of major importance to properly close the service chain.

5. Conclusions

The present work is based on an actual event—the "EXE.Lomb.Est 2023" earthquake response exercise conducted during the Civil Protection Week in the Lombardy Region of Italy in October 2023—and contributed to the bridging of primary research data and practical evidence. This type of study, grounded in real scenarios, features the added value of validating theoretical models and assessing the effectiveness of technological applications in optimizing emergency response systems. In that, the described exercise was an important opportunity to pool collaboration between research bodies and institutions and made it possible to implement and test a UAS service chain that (1) starts from the activation mechanisms; (2) through the application of operational technical solutions, is able to satisfy the needs of stakeholders in times compatible with an emergency situation; and (3) is fully integrated within the overall emergency response system.

The conduct of the exercise has been analyzed for the two macro-areas of experimentation (activation management and emergency aerophotogrammetry) in terms of strengths, weaknesses, opportunities and threats.

Within the perspective of the former aspect, the experimentation of the coordination system basically worked and proved to be useful and effective in response, even if some critical issues or some aspects for improvement were identified, mainly concerning the communication flows and formats. Noteworthy is the involvement of the national aviation authorities (ENAC/ENAV/D-flight), which has opened an essential dialogue to be kept active and operational in the near future.

Regarding the conduct of joint technical activities, a great synergy developed among the involved teams from different institutions in elaborating shared procedures, common language and brainstorming on needs and solutions. Some critical issues and some aspects deserving further attention and experimentation were also highlighted, mainly concerning the safety with respect to interference with manned flights without transponders and the final delivery of products to the stakeholders. In this regard, it is noteworthy that an added-value service chain is really such only if properly concluded, which means making the produced output "ready to use" and operational. Given the nature of the described technical products, their usability is directly proportional to the technical level of the end users, to the adequate information on the type and quality of the contents made available, highlighting their limits, assumptions and conditions, as well as the availability of sufficiently high-performance technologies for an adequate visualization. As an example, a cloud-service platform designed according to end users' requirements with specific access permissions would ease this last step of the chain. This can be obtained only through a sort of trial-and-error interactive process with pilot stakeholders since the platform needs to be customized based on an evolving given portfolio of outputs, properly considering also aspects of data protection, bandwidth and so on.

It can be said that the system, as a whole and in its various aspects, certainly worked and was an excellent opportunity to operationally put the various "forces at play" into action. Likewise, and as expected, it emerged that the system itself needs to be "run in", optimized and further tested.

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List of Acronyms and Abbreviations

Acronyms/Abbreviations	Definition
AGL	Above ground level
ARPA Lombardia	Regional Agencies for Environment of Lombardia
ARPA VDA	Regional Agencies for Environment of Valle d'Aosta
ARPACAL	Regional Agencies for Environment of Calabria
CB	Coordination base on site
CCOA	Coordination center of overall air operations
CIMA	International Center for Environmental Monitoring
CNR	National Research Council
CNVF	National fire brigades
CONOPS	Concept of operation
CSC	Combination stick command
DEM	Digital elevation model
DMS	Disaster management system

GCP	Ground control point
GSD	Ground sampling distance
INGV	National Institute of Geophysics and Volcanology
IT-STSs	Italian standard scenarios
MTOM	Maximum take-off mass
NFZ	No-fly zone
RTH	Return-to-home
RTK	Real-time kinematic
UAS	Unmanned aerial system
UAS CCT	Technical coordination center of the external UAS networks
UNIFI	Civil Protection Center of the University of Firenze
VLOS	Visual line of sight

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