ГЕОДЕЗІЯ ТА ЗЕМЛЕУСТРІЙ. МОНІТОРИНГ ТА ОХОРОНА ЗЕМЕЛЬ

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METHODOLOGY FOR ORGANISING THE PROCESS OF COLLECTING CONSOLIDATED EVIDENCE FOR THE RUINATION REGISTRY USING AERIAL PHOTOGRAPHY

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Abstract. *The armed aggression of the russian federation against Ukraine has led to significant destruction of the residential and municipal infrastructure of cities and towns not only in the occupied territories, but also in territories throughout the country due to massive rocket attacks. The problem of damage estimation for people who have lost their homes or have partial damage to their homes has a priority status, as the number of people staying in the streets is constantly growing, and social temporary housing is running out of space, as it is becoming permanent for them. Therefore, any state initiatives to compensate or rebuild people's housing and restore municipal institutions and facilities that are important for the restoration of normal life in the de-occupied territories and territories of the country that suffer the greatest damage from aggression should find active support, both practical and analytical, among the scientific community and legal entities that are able to implement the state's initiatives in a short time. Thus, the article proposes a methodological framework for the practical implementation of the state initiative to effectively and substantiated by factual evidence (aerial photographs, orthophotographs, vectorised and decoded typical signs of destruction) allocate funds for the restoration and reconstruction of damaged property to people who have experienced material losses and have no place to live.*

The purpose of the study is to develop a methodology for collecting and cataloguing consolidated evidence for the register of destruction using aerial photography, taking into account all stages and types of work in the conditions and with regard to the conduct of hostilities.

The main objectives of the study are: to analyse existing methods for determining the geometric characteristics of the consequences of military shells hitting buildings; to determine the relationship between the force of the explosion and the geometric characteristics of damage; to develop a methodology for determining the degree of damage to a building and assessing damage; to create and implement technologies for processing and cataloguing typical damage data; to develop forms of reporting documentation based on the data sets obtained, taking into account the further needs of the state; to test the developed methodology in practice.

The developed methodology will optimise the process of obtaining and processing the necessary data from the mission planning stage to the damage assessment stage, based on the processed data and technical reports of the analyst team by creating a single and universal methodology that minimises numerous differences in the standardisation of input data, will create a single effective data collection system throughout the country and will accelerate the process of recording and confirming cases requiring state intervention at the state level. The effectiveness and accuracy of the proposed methodology is due to the modern software and analytical products of geoinformation technologies and effective technological means of field work for obtaining remote sensing data.

Keywords: *damage, aerial photography, unmanned aerial vehicles, remote sensing of the Earth, military aggression by russia.*

Relevance

As of January 2024, the military aggression against Ukraine has caused enormous losses, estimated at approximately $155 billion [1]. These estimates are approximate and not final. Post-war reconstruction requires an accurate assessment of the losses incurred by Ukraine due to the destruction of infrastructure as a result of hostilities. Quantitative indicators of material damage are needed to determine the amount of reparations.

Considering the level of destruction, the most heavily damaged settlements are those where military operations took place, i.e. where the front line passed through these areas. The more static the front line, the greater the degree of destruction. Accordingly, in areas where hostilities have been ongoing for a long time, the degree of destruction can reach 95-100% [2]. Consequently, the amount of damage to infrastructure in these areas is the highest.

It should be noted that in places located far from the combat zone, damage or destruction of buildings is recorded directly by the relevant authorities with minimal risks. In the de-occupied territories where active hostilities took place, there is a problem of recording these crimes and further calculating damages due to the mine danger and a significant number of destroyed objects. In order to solve this problem, aerial photography from unmanned aerial vehicles (UAVs) can be effectively used.

Consequently, the task of developing a methodology for collecting and

cataloguing consolidated evidence for the registry of destruction using aerial photography, taking into account all stages and types of work, is currently relevant and important for the country.

Analysis of recent surveys and publications

The issue of planning aerial photographic works for various applied tasks has been studied by many researchers, among them it should be noted Pilicheva M.O., Masliy L.O. [3], Jamieson A., Bassett I., Hill L., [4], etc. In their studies, they have shown the effectiveness of using aerial photography data for the rational solution of scientific and practical problems.

Komnatnyi S. [5], Anisimova A. [6], Didukh Y. [7] and others have assessed the damage caused by military aggression to settlements. It should be noted that for the most part, the developed methods of damage assessment are based on the inspection of buildings and structures directly on the ground. A large amount of destruction and mine danger complicates the contact method of research, so the use of aerial photography data from UAVs allows for a quick and safe determination of material damage from military operations.

The purpose of the study. The objective of this research is to enhance the operational efficiency of the data collection process for determining the damage caused to the buildings in the de-occupied territories under martial law by implementing aerial photography using UAVs, processes and technologies for processing the data obtained to support and make management decisions.

To achieve this goal, the following technical tasks were formulated and fulfilled:

- development of procedures to address current problems with the collection, verification, analysis and assessment of civilian infrastructure losses in the de-occupied territories of Ukraine: collection of relevant information on hostilities in the region, study and assessment of the original survey and mapping documentation, documentation of field topographic and geodetic works, photographic survey of the territory, preliminary processing of the collected mapping information, production of an orthoimage, vectorization of the orthoimage, interpretation of data based on vectorization.

- development of a functional block of the geographic information system for further processing with high-quality orthophotos and a geodatabase of destructions, which will in the future allow making managerial decisions regarding to the post-war reconstruction of the country, and will also become a legal information and evidentiary basis for further legal protection of the rights of Ukraine and its citizens in international courts against the aggressor country.

Materials and methods of the study

In the course of the study, the data obtained will be sorted into direct and indirect losses from a full-scale war in Ukraine on the example of the de-occupied territories.

To describe the developed methodology, the entire process was divided into six main stages as shown in Fig. 1.

The first stage involves agreeing on the terms of reference (ToR) for the project. To assess the damage, the ToR is formed according to the requirements of the "Russia Will Pay" project [3]. Numerous organizations, includ-

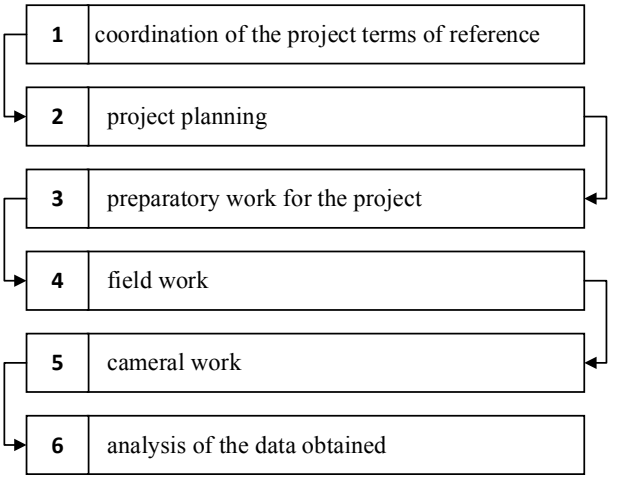

Fig. 1. Stages of the developed methodology

ing the KSE Institute, Dragon Capital, and others, with the support of USAID, are engaged in evaluating the damage in Ukraine [8]. The formulation of the technical specifications for aerial photographic operations is predicated upon the stipulations of the extant Ukrainian legislation.

Initial data from the employer: boundaries of the surveyed area in DMF, SHP, KML format in the WGS 84 international coordinate system without an elevation base.

Requirements for aerial photographic equipment, UAV equipment parameters and imaging technology:

To obtain digital images, a digital frame camera with an image size of at least 60 megapixels must be used. The relevance of the photographic materials should be no earlier than the date of de-occupation of the settlement. The geometric resolution of the photos is 5-7 cm/pixel. The minimum longitudinal and transverse overlap of photographs in the service area is at least 70%. Digital imagery should cover the entire territory of the study area and have a buffer zone of 100 meters along the boundaries of the settlement. Use of a GNSS system to accurately position the trajectories of the aircraft, further referred to as UAVs. The result of aerial photography should be color images in RGB format with 8-bit representation of each channel. These images must have correct color reproduction, as close as possible to the real appearance of the territory being surveyed.

Aerial photography is to be performed under conditions that exclude the influence of environmental factors that may prevent clear view of terrain details, except for leaf cover on trees, snow cover, cloud shadows, fog and smoke, except for smoke resulting from continuous production.

Requirements for the creation of a planned elevation network of features

The coordination and determination of the heights of features is carried out by means of GNSS observations, in RTK or VRS mode using dual-frequency GNSS receivers. Two types of reference points are used for GNSS observations and control: the permanent

network and the State Geodetic Network (SGN). The accuracy of the features should not exceed 10 centimeters of the planned position. All points of the SGN are subject to survey. In order to coordinate the features, it is necessary to select objects on the ground that are easy to decode. In case of their absence, markings on the ground should be used prior to the surveying of the territory.

Photographic fixation of reference and control points is held in such a way that the position of the GNSS receiver center is clearly visible in relation to other objects on the ground. Control points are determined in the same way as reference points, but they are not involved in balancing aerial images. According to regulatory documents, the number of control points should be at least 10% of the total number of reference features. The urban geodetic network should also be linked to the State Geodetic Reference System in the working area - WGS 84.

Requirements for finished orthophoto maps

Geometric resolution should be within 5-7 cm/pixel or more. The average square error of orthophoto plans should not exceed 2 pixels on flat terrain. The maximum permissible values of contour misalignment when merging with neighboring sheets of orthophoto plans should not exceed 4 pixels. To create orthophotos used in editing, it is necessary to use the central part of aerial images to minimize perspective distortions and errors related to the terrain. All ground objects should be displayed with accurate coordinates corresponding to their actual location. When creating orthophotos, specialized algorithms should be used to automate the processing of dead zones caused by high-rise objects. A slight offset of high-rise objects, such as tower structures, from their true position is allowed. Areas that are not visible in the orthoimage due to the tilt of high-rise objects should be restored using other images where these areas are visible.

As Ukraine is in a full-scale war, there are special conditions for aerial photography. In conformity with the stipulations of the Ukrainian Air Code and the directives governing the utilization of Ukrainian airspace as mandated by the Civil Aviation Authority and the State Aviation Service of Ukraine, measures have been taken to close Ukrainian airspace to civilian users and suspend the provision of air navigation services. If the State Aviation Service of Ukraine extends the period of suspension of access to the airspace for civil aviation, which makes it impossible to conduct aerial photography, it is allowed to use unmanned UAVs to perform the necessary work.

All forms of imagery, as delineated within the methodological framework, must be procured in strict adherence to the Ukrainian legislative and regulatory mandates concerning the safeguarding of state secrets, as well as in accordance with the ‘Aviation Rules of Ukraine’ pertaining to the utilization of airspace, which were ratified by the conjoint directive of the State Aviation Service of Ukraine and the Ministry of Defense of Ukraine, under the decree dated May 11, 2018, No. 430/210, and subsequently registered with the Ministry of Justice of Ukraine on September 14, 2018, as No. 1056/32508 [9].

To ensure the technical feasibility of the work and the use of UAVs, the contractor is obliged to obtain permits from the General Staff of Ukraine or other relevant authorities. Carriers containing aerial photographic data are subjected

to regulatory oversight as mandated by extant Ukrainian legislation, enforced by competent state entities. This protocol is imperative for the classification of information necessitating protection within premises overseen by the Ministry of Defence of Ukraine, the Armed Forces of Ukraine, and ancillary security and defense forces, culminating in the formulation of an appropriate documentary attestation.

The process of acceptance and approval of the results of the work performed is carried out by the Customer in accordance with the regulatory requirements established by the Law of Ukraine 'On Topographic, Geodetic and Cartographic Activities', based on the assessment of the quality and compliance of the work performed with the established criteria.

In accordance with the requirements of Article 19 of the Law of Ukraine 'On Topographic and Geodetic Activities', the Contractor is obliged to submit to the State Cartographic and Geodetic Fund of Ukraine one copy of all geodetic, topographic, cartographic and aerial survey materials created. Such procedures must be executed in compliance with the regulatory framework governing the reception, preservation, utilization, and documentation of materials from the State Cartographic and Geodetic Fund of Ukraine, as sanctioned by the Cabinet of Ministers of Ukraine on July 22, 1999, under decree No. 1344 [10]. The result of the first stage will be a finished technical task.

The second stage is the project planning. For a project to collect, process, assess, and analyze information on Ukraine's material losses from a full-scale war with the Russian Federation, the project planning block sets the cost of work, i.e. the working hours of all departments and the scope of work, administrative costs for housing, travel, fuel, food, etc., depreciation of technical equipment, software, and margin, prepares tender documents, determines the settlements to be surveyed, and selects the locations to be surveyed. After that, the working teams of pilots and surveyors are formed, travel orders are drawn up, and the best routes to the work site are searched for and accommodation is found. The result of the second stage is a developed project plan.

The third stage is the preparatory work, which begins after the agreed project plan based on the ToR. A diagram of this stage is shown in Fig. 2.

The functional block "Organizational and Legal Relations" (Fig. 2) provides an algorithm for obtaining a permit to fly UAVs. This procedure is conducted through the submission of a request for the execution of specific types of work in de-occupied territories, based on a memorandum between the Kyiv School of Economics, the Office of the President of Ukraine, the Ministry of Economy, and others [8]. The formed letter is sent to the General Staff of the Armed Forces of Ukraine, the relevant headquarters of the Operational and Strategic Military Grouping ("OSMG"), regional military administration ("RMA"), district military administration ("DMA"), united territorial community ("UTC"), city or village council where aerial photography is planned to be conducted. In parallel to this procedure, a letter requesting evidence of destruction in the community is sent to the RMA, DMA, UTC and settlement in the same manner as described above. As a result, two response letters are received, the first one on permission to carry out work using aerial photography and the use of UAVs, and the second one on confirma-

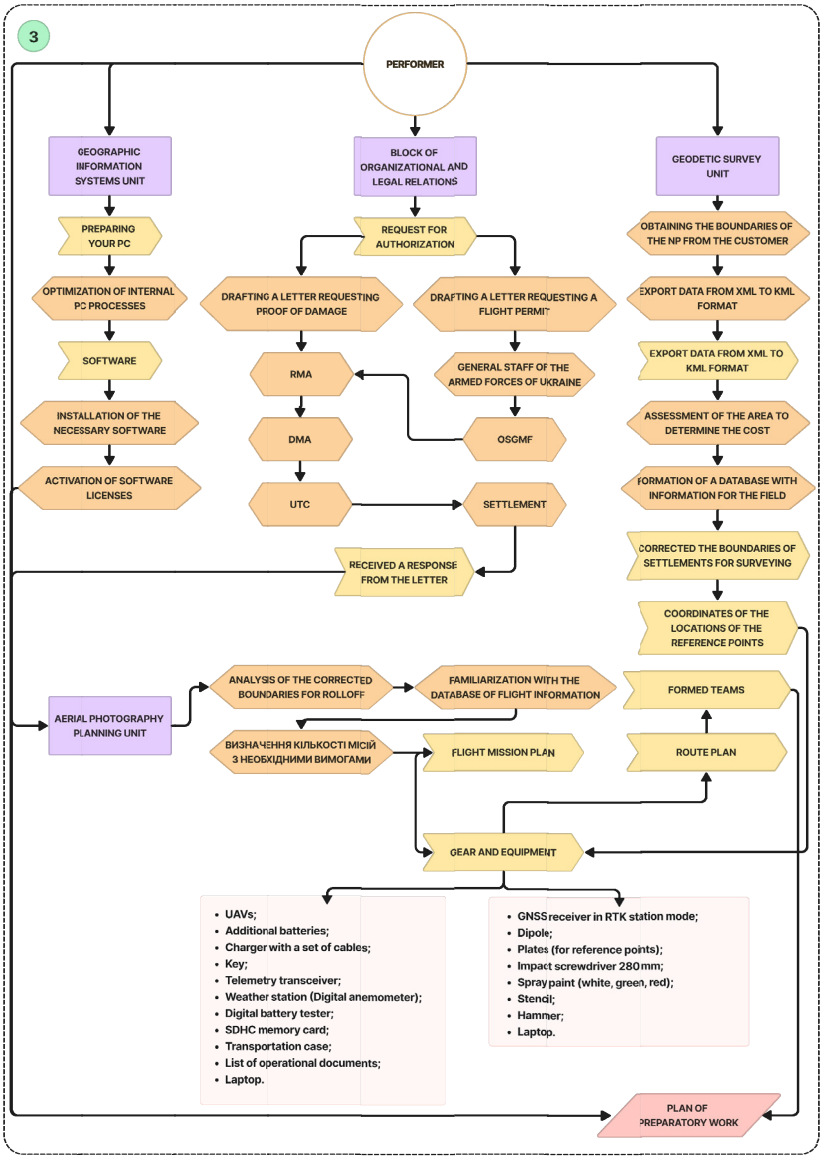

Figure 2. Flowchart of the preparatory stage of the work

tion of destruction in the settlement.

The "Geodetic Survey" block includes the process of determining the boundaries of settlements (according to the client's initial data) - for further determining the scope of work, creating a database with information on the parameters of the flight mission. Next, the boundaries of the settlement are adjusted and the approximate coordination of reference and control points is determined.

The "Aerial Survey Planning" block includes analysis of the corrected

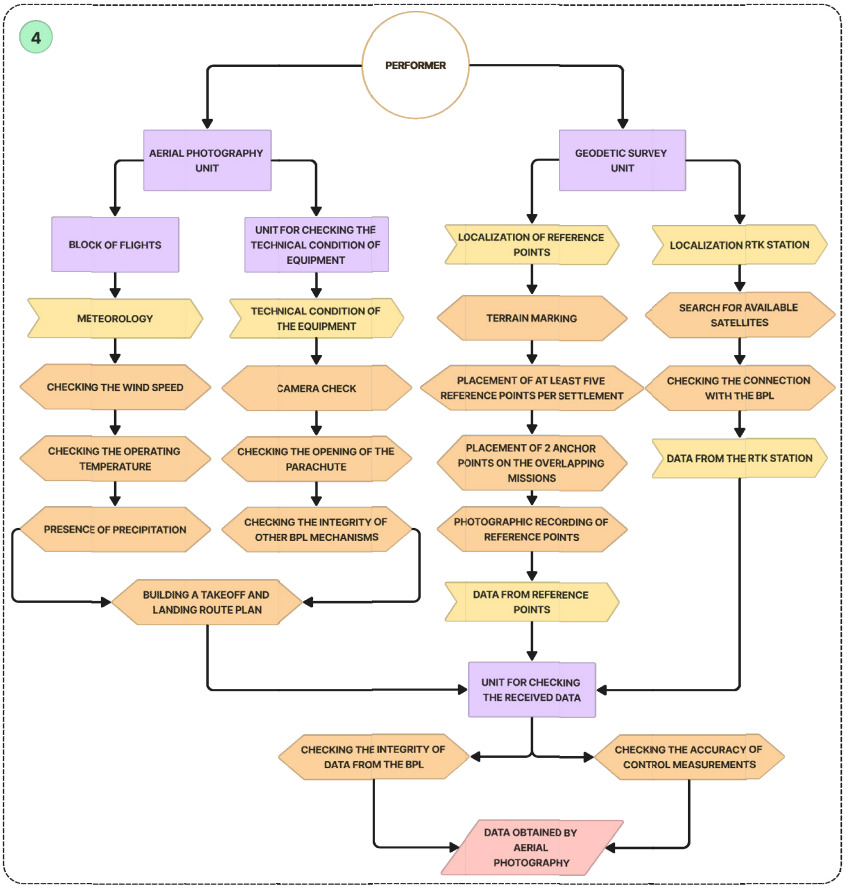

Fig. 3. Flowchart of the fieldwork stage

boundaries of the settlement, analysis of the database with information on flight missions, determination of the number of flight missions depending on the area and configuration of the settlement or UAV type. Next, a flight mission plan is developed. After that, the necessary equipment is selected to perform all types of work on this project.

The Geographic Information Systems block includes the preparation of personal computers and installation of the necessary software for further project implementation.

As a result of all the blocks of the second stage, a plan of preparatory work is formed.

The fourth stage is fieldwork (Fig. 3). This is the key stage on which the possibility of performing all further work depends. Based on the previous stages, a team is formed to conduct aerial photography on the ground.

The "Geodetic survey" block includes localization of the station's RTK to search for available satellites for more accurate georeferencing of images during the UAV flight, as well as localization of reference points on characteristic places, or marking the terrain

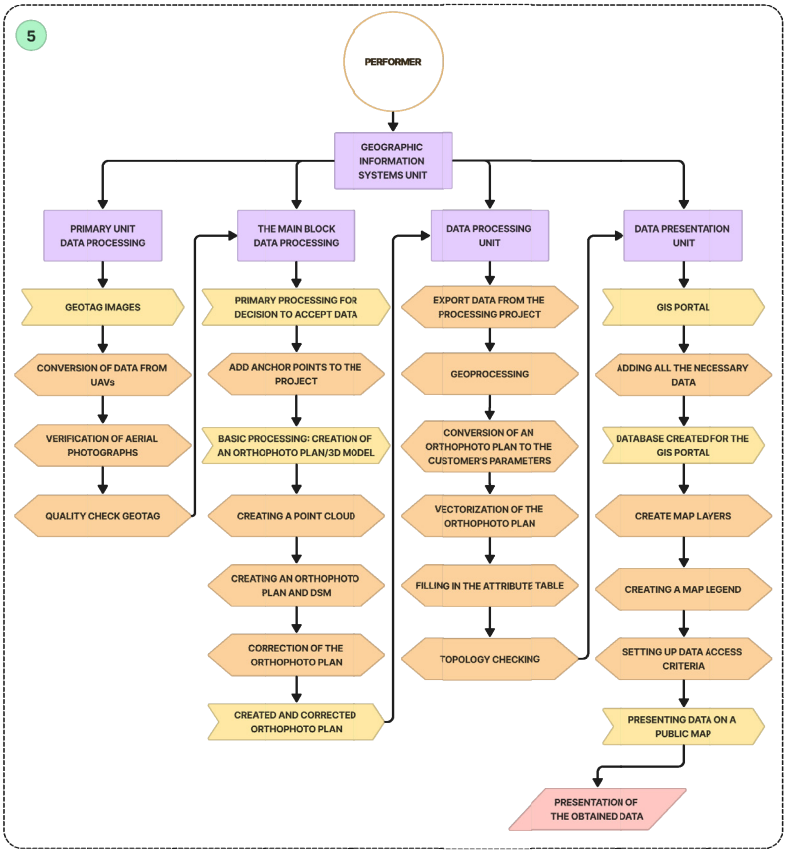

Fig. 4. Block diagram of the stage of cameral work

with photographic fixation of reference features. All received data from the RTK station and the GNSS receiver are checked on site for gross errors.

The "Aerial Photography" block includes checking the technical condition of the equipment, namely the camera, the parachute opening mechanism, and the integrity of other UAV mechanisms. Weather conditions are also checked before the start of the flight mission, including wind speed, operating temperature, and precipitation. The last step before launching a UAV is to build a takeoff and landing route map.

At the end of the flight mission, the integrity of the data obtained from the UAV is checked and as a result of the fourth stage, we have data obtained through aerial photography and geodetic measurements to improve the accuracy of the future orthophoto.

The fifth stage is the desk work (Fig. 4). At this stage, all the data from the fieldwork stage is processed. Based on the results obtained, data is collected and provided for further damage assessment.

The entire scope of work in desktop data processing is performed by the

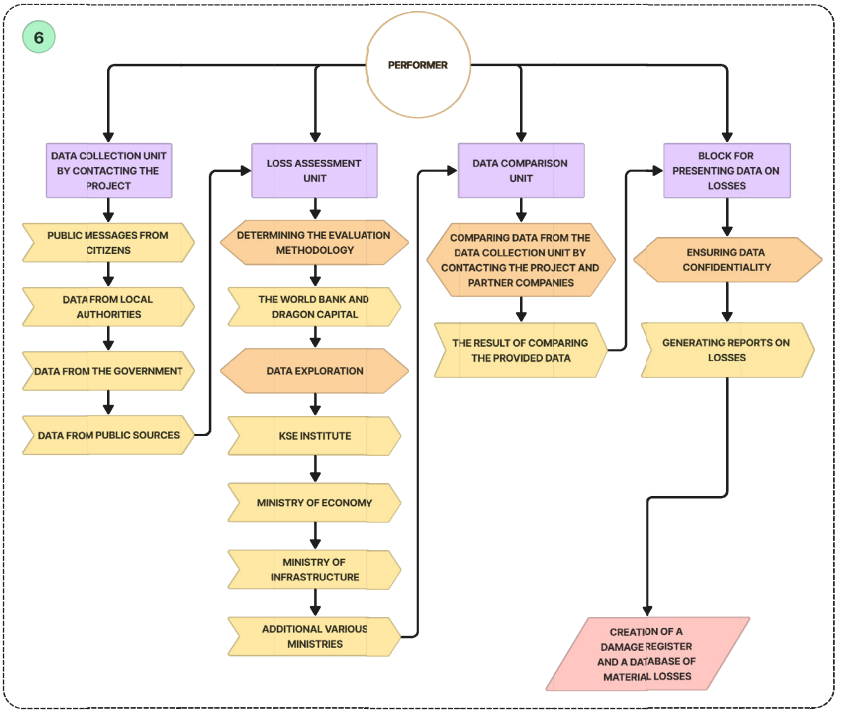

Fig. 5. Block diagram of the stage of cameral work

Geoinformation Systems unit. At the beginning, the process of adding geographic metadata to the images (geoteg) is carried out. After satisfactory geotagging results, the quality of the aerial images is checked in accordance with the requirements of the technical specifications.

Next, an orthophoto map is created using internal and external orientation elements (geotag) and the georeferencing of the images to the ground network of the planning and elevation justification is specified. During the geoprocessing of the images, a point cloud is created, which is the basis for creating an orthophoto plan and a digital terrain model (DSM). Next, the orthophoto plan is geoprocessed according to the technical specifications.

Based on the obtained orthophoto map, the damaged buildings are vectorized and the attribute table is filled in the database. Upon completion of the vectorization process, the topology is checked.

The obtained data is uploaded to the geoportal, which is configured to correctly display all map layers, create a legend, and set up the level and access parameters. The data from the geoportal will be used for further damage assessment.

The sixth stage is the analysis and evaluation of the data (Fig. 5). This stage begins with a data collection block by contacting the project through public messages from citizens, data from local authorities, the government, or public sources.

The block "Assessment of losses" defines the methodology for their calcula-

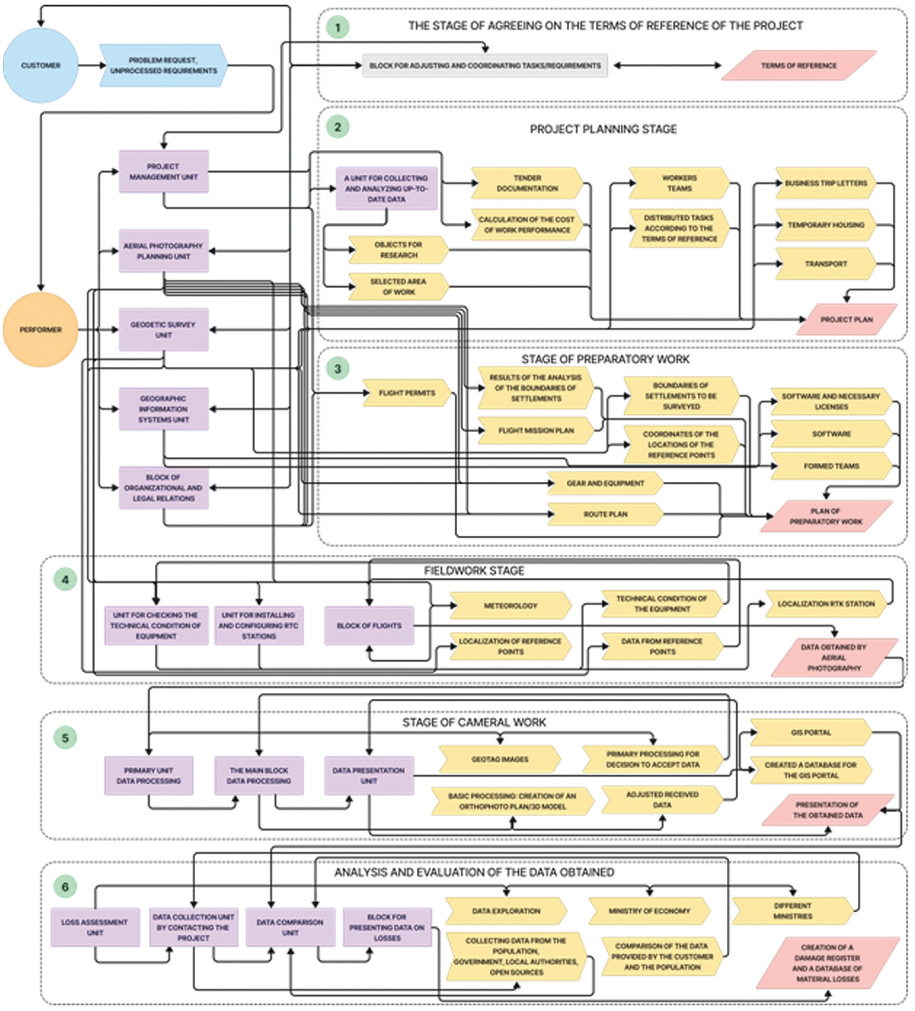

Fig. 6. Block diagram of the stage of cameral work

tion based on the experience of the Kyiv School of Economics and others [8].

The next block is a comparison of data obtained from citizens, local authorities, the government, and public sources with the data provided to the company by the project participants who performed the aerial survey.

Based on the data obtained, a block for presenting data on losses is formed, which takes into account the confidentiality of all the data provided and creates a register of damage and databases on material losses of Ukraine from the war with the aggressor.

Thus, the final version of the methodology for collecting, processing, evaluating and analyzing information on direct and indirect damage from a full-scale war in Ukraine on the example of the de-occupied territories is shown in Figure 6.

Figure 7. Fragment of the aerial map of Posad Pokrovske village

Results of the study

This methodology has been practically implemented on the example of the de-occupied settlement of Posad-Pokrovske in Kherson region, which is included in the list of six settlements to be rebuilt according to the new principles of "Better than before," i.e., restoration of the entire infrastructure with a systematic approach.This settlement is almost completely destroyed (Fig. 7).

According to the developed methodology, the orthophoto plan was vectorized with filling and cataloging of attributive information related to the object. An example of vectorization of an orthomosaic is shown in Fig. 8. For each building, the type, number of storeys, address, level of destruction, etc. are specified. All defined data of the vectorized objects are stored in the form of spreadsheets that are part of the structure of shapefiles of geospatial layers. In the future, these materials will serve as the information basis for creating geospatial databases that will allow making management decisions on the post-war reconstruction of the country. In this form, the obtained geodata will have evidential legal force to further protection of the rights of Ukraine and its citizens in international courts against the aggressor country.

The next step is to provide the data to the relevant institutions responsible for analyzing and assessing the damage. In the village of Posad-Pokrovske, it was determined that out of 4,140 civilian infrastructure objects, 826 (19.7%) were completely destroyed, 1,016 (24.5%) buildings were severely damaged, 394 (9.6%) were moderately damaged, and 556 (13.5%) buildings were possibly damaged.

The acquired data is conveyed to the analytical center at the Kyiv School of Economics, wherein the collated information undergoes scrutiny, culminating in the production of a report delineating the losses.

Conclusions and prospects

The developed methodology helps to increase the efficiency of filling the

Figure 8. Vectorized orthophoto map of Posad Pokrovske village

unified state register of material and technical damage to municipal and private property in de-occupied cities and suburbs of Ukraine, to quickly and safely obtain decoding signs and characteristics of damage. The algorithm for conducting all the necessary types of work to achieve this goal can be automated by implementing the analytical parts of the system in complex geographic information systems, which will also increase the efficiency of processing a large amount of input data in the future. This prospect will make it possible to organize a more rapid recording of victims of hostilities, which in turn will become the legal basis for providing assistance to people who lost their homes as a result of hostilities and will be the starting point for reconstruction and recovery programs.

In the future, the proposed technologies can be used both to gather substantiation of war-related transgressions committed by russia, determine material damage from the war, and control the quality of future post-war construction projects, as well as to monitor the current state of important municipal facilities in future construction projects of restored cities.

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МЕТОДИКА ОРГАНІЗАЦІЇ ПРОЦЕСУ ЗБОРУ ЗВЕДЕНИХ ДОКАЗІВ ДЛЯ РЕЄСТРУ РУЙНУВАНЬ ЗА ДОПОМОГОЮ АЕРОФОТОЗЙОМКИ

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Анотація. *Збройна агресія російської федерації проти України призвела до значних руйнувань житлової та муніципальної інфраструктури міст та селищ не тільки на окупованих територіях, а й на територіях по всій країні через масовані ракетні обстріли. Така проблема як оцінка збитків для людей які втратили житло, або мають часткові пошкодження житла, має пріоритетний статус, адже кількість людей що залишаються просто неба постійно зростає, а соціальне тимчасове житло закінчується, бо стає для них постійним. Тому будь які державні ініціативи щодо відшкодування, або відбудови житла людям та відновлення муніципальних установ та споруд, що є значущими для відновлення нормального життя на деокупованих територіях та територіях країни що зазнають найбільшої шкоди від агресії мають знаходити активну підтримку як практичну, так і аналітичну серед наукової спільноти та юридичних осіб, які здатні у короткий час втілювати ініціативи держави в практичну площину. Таким чином в статті*

запропонована методологічна основа для практичного втілення державної ініціативи на ефективний та обґрунтований фактологічними доказами (аерофотознімками, ортофотопланами, відвекторизованими та віддешифрованими типовими ознаками руйнувань), розподіл коштів на відновлення та відбудову пошкодженого майна людям які зазнали матеріальних втрат та не мають де жити.

Метою дослідження є розроблення методики збору та каталогізації зведених доказів для реєстру руйнувань за допомогою аерофотозйомки із урахуванням всіх етапів та видів робіт в умовах та з урахуванням ведення бойових дій.

Головні завдання дослідження: аналіз існуючих методів визначення геометричних характеристик наслідків влучання військових снарядів в будівлі; визначення залежності між силою вибуху та геометричними характеристиками пошкодження; розробка методики визначення ступеню пошкодження будівлі та оцінки збитків; створення та впровадження технологій обробки та каталогізації типових даних щодо пошкоджень; розробка форм звітної документації на базі наборів отриманих даних з урахуванням подальших потреб держави; практична апробація розробленої методики на прикладі реальної тестової ділянки деокупованої території.

Розроблена методика дозволить оптимізувати процес отримання та обробки необхідних даних починаючи з етапу планування місії, закінчуючи етапом оцінки збитків, спираючись на оброблені дані та технічні звіти команди аналітиків за рахунок створення єдиної та універсальної методики, що мінімізує багаточисельні відмінності у стандартизації вхідних даних, дозволить створити єдину ефективну систему збору даних по всій території країни та прискорити процес фіксації та підтвердження на державному рівні випадків, що потребуватимуть втручання держави. Ефективність та точність запропонованої методики обумовлена закладеними до її основи сучасними програмно-аналітичними продуктами геоінформаційних технологій та ефективними технологічними засобами польової роботи для отримання даних ДЗЗ.

Ключові слова: *збитки, аерофотозйомка, БпЛА, ДЗЗ, військова агресія рф.*