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ARTICLE

Application of Orthophoto Maps Created from UAV Aerial Images for Monitoring Historical and Cultural Heritage Lands

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ABSTRACT

The study investigates the methodology of creating orthophotoplans for immovable historical and cultural heritage sites, beginning from aerial surveys using various UAVs to object vectorization and plan creation. This issue is highly relevant in Ukraine due to rapid reforms in all ministries, including the Ministry of Culture. The reforms are creating a constant need for updated graphical documentation. As immovable historical and cultural heritage sites are in tourist areas with changing infrastructure, traditional surveying methods are impractical due to time constraints. Additionally, the application of UAV aerial imaging for delineating object boundaries and protective zones is more cost-effective. Existing boundaries of heritage lands and those determined from archival materials were overlaid on the created pflans. Orthophotoplans were produced and vectorized at a scale of 1:500 for two research zones: the Holy Trinity Church in Liuboml and the New Jewish Cemetery in Lviv. For the New Jewish Cemetery, boundaries were delineated to assess alignment with the current protective zone. Protective buffer zones around heritage sites were outlined according to both historical and contemporary recommendations in Ukraine. For buffer zones measured from the centroid, development is permitted up to 300 meters for undeveloped areas, with negotiated distances for developed regions, using the 300-meter protective zone as a baseline. The study's uniqueness lies in using a known methodology for creating orthophotoplans based on UAV data to explore options for modeling protective zones based on varying legislative norms over time, incorporating specific nuances. This approach can benefit not only Ukraine but also other countries undergoing reforms in this field.

Keywords: Lands of historical purpose; Aerial survey; Orthophotoplans; Historical boundaries; Protective zone; Cultural heritage; Monitoring of lands

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1. Introduction

The category of lands, especially protected territories, which include lands of historical and cultural significance, is a public asset. At the same time, objects of historical and cultural significance serve as historical sources. The Ukrainian state acts as a guarantor of the preservation of these lands by designating them as a special category and establishing a unique legislative regime for their use. Thus, within the framework of monitoring of land and objects of historical and cultural purposes, observations should be conducted both on the state of historical-cultural heritage sites and on the lands designated for historical-cultural purposes where they are located. Probably, only in this way, it is possible to effectively monitor lands and objects of historical and cultural purpose.

The historical and cultural processes that took place in any specific geographical area are largely determined by the physical-geographical and climatic features of the region, and are reflected in its landscapes. Information about these processes is stored in immovable historical and cultural monuments and in the unique form of anthropogenic landscapes. As a result, the features of historical and cultural objects provide the researcher with important typological features for the classification of lands of historical and cultural purpose.

The first group of observations carried out during the monitoring of lands and objects of historical and cultural purpose should be studies of the dynamics of the boundaries of land plots (monitoring of the boundaries of lands of historical and cultural purpose). In the current legislation, the term "monument protection zone" is used to designate a section of the territory related to a historical and cultural monument, which actually means: a protection zone, a development regulation zone, and a protected natural landscape zone. In each zone, the law stipulates different restrictions for land users, while the boundaries of these zones may not coincide. As a matter of fact, the territory of the monument is only one of the zones listed above—the protected zone of the monument. It is advisable to summarize information about the geometric characteristics of the land plot in the form of its plan on a scale of 1:500 for objects located within settlements, and on a scale of 1:2000 for objects located in uninhabited territories. In addition to creating a plan, the area of the land plot must be calculated, its borders described, and the coordinates of the turning points of the borders determined. This information is initially obtained during basic monitoring.

Monitoring of the boundaries of land plots and objects of historical and cultural purpose is carried out using aerial imaging and ground geodetic surveying.

The second group of observations, which should be carried out during the monitoring of lands and objects of historical and cultural purpose, is related to the assessment of the qualitative state of these lands and the objects located on them.

To monitor lands and objects of historical and cultural purpose, it is most appropriate to use the following practical methods: (i) remote sensing, including aerial imaging from a UAV; (ii) subsurface remote sensing (ground-penetrating radar imaging, etc.). This study aims to evaluate the effectiveness of UAV technology in the preservation of historical and cultural heritage sites in Ukraine.

Determining the historical boundaries of objects of historical and cultural heritage plays an important role in establishing their protection zones and the boundaries of lands of historical and cultural purpose.

According to Article 54 of the Constitution, cultural heritage is protected by law [1]. In Ukraine, legal, organizational, social, and economic relations in the field of cultural heritage protection are regulated by the Law of Ukraine "On the Protection of Cultural Heritage" No. 1805-III dated June 5, 2000 (as amended) (hereinafter referred to as the Law) [2]. Pursuant to Article 3 of this law, state management in the field of cultural heritage protection is entrusted to the Cabinet of Ministers of Ukraine and specially authorized bodies for the protection of cultural heritage.

Key acts defining the directions for implementing state policy in the field of cultural heritage protection include the Association Agreement between

Ukraine, on the one hand, and the European Union, the European Atomic Energy Community, and their member states, on the other hand, ratified with the Law of September 16, 2014, No. 1678-VII, and the Medium-Term Action Plan of the Government until 2020 and priority action plans of the Government, approved by the Cabinet of Ministers of Ukraine's decree of April 3, 2017, No. 275-r [3].

The existing number of immovable cultural heritage objects in Ukraine currently on state registration is over 170,000 objects of cultural heritage. These are objects of cultural heritage entered into the State Register of Immovable Monuments of Ukraine; objects of cultural heritage recorded in accordance with the legislation that was in force before the enactment of this Law until the issue of inclusion (non-inclusion) of the object of cultural heritage in the State Register of Immovable Monuments of Ukraine is resolved, and objects of cultural heritage until the issue of their registration as monuments included in the List of Objects of Cultural Heritage and acquiring the legal status of newly discovered objects of cultural heritage.

The use of Unmanned Aerial Vehicles (UAVs) in the study of cultural and natural heritage is highly diverse and depends on geographical zones and types of heritage. Here are several case studies that demonstrate the use of UAVs in different regions and for various types of heritage.

(i) Archaeological research in South America. Machu Picchu, Peru [4]:

UAVs have been used to create highly accurate 3D models of this famous archaeological complex. Thanks to drones, detailed aerial images and modeling data were obtained, allowing archaeologists to better understand the structure and dimensions of the ancient Incan city.

(ii) Cultural heritage preservation in Europe. Château de Chambord, France:

Drones were employed to gather data from hard-to-reach areas to create digital models of Château de Chambord. This ensured precise documentation of architectural details and facilitated restoration efforts, preserving the historical heritage.

(iii) Natural heritage and ecosystem conservation in Africa. Serengeti, Tanzania [5]:

In Serengeti National Park, UAVs were used to monitor wildlife populations and combat poaching. Drones allow for the rapid and effective tracking of large mammal movements and the detection of illegal activities over vast areas.

(iv) Landscape documentation and monitoring in North America. National Parks of the USA [6]:

UAVs are used for mapping and monitoring changes in national parks such as Yellowstone and Yosemite. They help track changes in vegetation cover, the impact of climate change, and ensure visitor safety.

(v) Study of traditional architecture in Asia. Temple complexes in Cambodia [7]:

At Angkor Wat and other temple complexes, drones have been used to create detailed maps and models, which assist in studying the structure of the temples, planning restoration works, and preserving architectural heritage for future generations.

These case studies demonstrate how UAVs can be effectively used in different geographical zones and for various types of heritage, ranging from archaeological sites to natural landscapes, and marine and cultural heritage.

It should be noted that the process of entering an object of cultural heritage into the State Register of Immovable Monuments of Ukraine is quite complex and time-consuming, complicated by the preparation of a significant amount of documents, sometimes duplicating each other, requiring significant financial expenditures for the production of mandatory documents.

Among Ukrainian scientists, a large number of people were engaged in determining the areas of lands of historical and cultural purpose and their protective zones, among which the following works should be noted. Bevz's study examines the establishment of executive bodies responsible for managing and safeguarding historical and cultural lands in Ukraine [8]. It discusses key elements such as the creation of specialized government agencies, development of legal frameworks, coordination among different levels of government, capacity building for personnel, public engagement strategies, and allocation of financial resources. The research aims to provide insights into the challenges and strategies involved in forming an effective system for the use and protection of historical and cultural lands in Ukraine. Legal aspects of defining the protection zones of lands of historical and cultural purpose are described in the work. Danilevsky and Danilevska research the criminal law aspects of the lands on which immovable cultural heritage objects are located [9]. It provides a detailed analysis of distinct legislative proposals aimed at enhancing the protection of such lands. Additionally, the study explores the legal framework governing lands designated for historical and cultural purposes. Through this analysis, the research sheds light on the intricacies of legal protection mechanisms for immovable cultural heritage sites, aiming to offer insights into effective strategies for safeguarding these invaluable assets [10].

The scientific and methodological principles and mechanisms of the organization and protection of lands of historical and cultural purpose, as well as their inventory, are considered in the works.

Gulkevich explores various avenues for enhancing the legal and institutional frameworks governing cultural heritage protection and environmental requirements within land management practices [11,12]. It examines strategies to improve the inventory of lands designated for historical and cultural purposes, emphasizing the importance of effective land management, cadastre [13], and land monitoring systems. Additionally, the study investigates the application of UAV photogrammetric methods in cultural heritage modeling, using the Kanlıdivane archaeological site as a case study [14]. Furthermore, it delves into advanced UAV techniques and the integration of Historical Building Information Modeling (HBIM) with UAV photogrammetry for the documentation and modeling of forgotten heritage sites, exemplified by the Isabel II dam in Níjar, Spain [15]. Through these case studies and methodologies, the research aims to contribute to the preservation and documentation of cultural heritage sites using innovative technologies and interdisciplinary approaches.

The study of Chetverikov and Babiy focuses on delineating the boundaries of ancient burial sites through the analysis of archived aerial and cartographic materials [16]. It presents a method for determining boundary shifts of the New Jewish Cemetery in Lviv using geoinformation systems [17]. Furthermore, it assesses the error estimation of Digital Elevation Models (DEM) derived from orthotransformed aerial images captured by UAVs in mountainous terrain, specifically in the village of Shidnytsya. Additionally, the research analyzes the effectiveness of UAVs for military applications [18]. Finally, it explores the mapping of cultural heritage sites in coastal areas using Unmanned Aerial Systems (UAS), with a case study conducted on Lesvos Island [19]. Through these investigations, the study aims to contribute to various fields, including archaeology, geoinformatics, and military reconnaissance, while also highlighting the potential of UAV technology for cultural heritage mapping and military operations [20].

The research of Baranwal et al. investigates the health monitoring and assessment of cultural monuments utilizing UAV image processing techniques. It delves into methods for prior calculation of the accuracy of monitoring cultural heritage objects using UAVs and laser scanning technologies, aiming to provide insights into effective strategies for maintaining and preserving cultural landmarks [21]. Through the utilization of advanced imaging and processing methods, the study contributes to the ongoing efforts to safeguard and conserve cultural heritage sites [22].

The research of Ergun et al. focuses on conducting a Level of Detail (LoD) geometric analysis of relief mapping through the utilization of 3D modeling derived from Unmanned Aerial Vehicle (UAV) images in cultural heritage studies [23]. By employing advanced UAV imaging techniques, the study aims to provide detailed insights into the topographical features of cultural heritage sites, contributing to a comprehensive understanding of their spatial characteristics. Through this analysis, the research seeks to enhance the documentation and preservation efforts of cultural heritage sites, utilizing innovative technologies for detailed geometric mapping and analysis.

The study of Knippschild and Zöllter explores urban regeneration initiatives in Eastern Germany, balancing cultural heritage preservation with revitalization efforts [24]. It investigates the implementation of a decision support tool to guide urban development projects in the region. Through case studies and analysis, the research evaluates the effectiveness of this tool in reconciling preservation goals with the need for urban renewal. By examining the experiences and outcomes of urban regeneration projects, the study aims to inform future strategies for sustainable development while safeguarding cultural heritage in Eastern Germany.

The research by Gil-Docampo et al. (2023) focuses on conducting 3D geometric surveys of cultural heritage sites using Unmanned Aerial Vehicles (UAVs) in inaccessible coastal or shallow aquatic environments [25]. It investigates the feasibility and effectiveness of UAV-based methods for capturing detailed geometric data of cultural heritage sites located in challenging terrains such as coastlines and shallow waters. Through the utilization of advanced imaging techniques and UAV technology, the study aims to provide accurate and comprehensive documentation of underwater and coastal archaeological sites, contributing to the preservation and understanding of cultural heritage in these environments.

Khelifi et al. study the use of autonomous service drones for multimodal detection and monitoring of archaeological sites [26]. It explores the potential of drones equipped with various sensors and imaging technologies to conduct comprehensive surveys and monitoring of archaeological sites. Through the integration of different detection modalities, including visual, thermal, and multispectral imaging, the research aims to enhance the efficiency and accuracy of archaeological fieldwork and monitoring activities. By employing autonomous drones, the study seeks to streamline the process of data collection and analysis, providing valuable insights into the preservation and management of archaeological sites.

The research by Masiri et al. focuses on producing and evaluating orthophoto maps using UAV photogrammetry techniques [27]. It explores the process of generating high-resolution orthophotos from aerial images captured by unmanned aerial vehicles. Through detailed evaluation, the study assesses the accuracy and quality of the orthophoto maps, aiming to validate the effectiveness of UAV-based photogrammetry for mapping applications [28]. By providing insights into the production and assessment of orthophoto maps, the research contributes to the advancement of UAV-based remote sensing technologies for various geographical and environmental studies.

Silwal et al. investigate the use of unmanned aerial vehicles (UAVs) for mapping and assess the accuracy of orthophotos, comparing results obtained with and without ground control points (GCPs) [29]. The study presents a case study conducted in Nepal, aiming to evaluate the efficacy of UAVs in generating accurate orthophoto maps for geographic studies in challenging terrains.

The study of Green et al. explores the utilization of low-cost UAVs for environmental monitoring, mapping, and modeling, focusing on applications in coastal zones [30]. Through examples, the research demonstrates the effectiveness of UAVs in capturing data for environmental assessments and coastal management initiatives.

Linchant et al. examine the potential of unmanned aircraft systems (UASs) in wildlife monitoring, discussing accomplishments and challenges in using UAVs for ecological studies [31]. The review evaluates the role of UASs in enhancing wildlife surveillance methods and highlights areas for future research and development.

Additionally, the research of Immerzeel et al. focuses on high-resolution monitoring of Himalayan glacier dynamics using unmanned aerial vehicles [32]. By employing UAV technology, the study aims to capture detailed imagery of glacier movements, contributing to a better understanding of glacier dynamics in the Himalayan region.

Furthermore, Laliberte et al. discuss the acquisition, orthorectification, and object-based classification of UAV imagery for rangeland monitoring [33]. Through these methods, the study aims to assess vegetation patterns and land use changes in rangeland areas, providing valuable insights for land management and conservation efforts.

Lastly, Pérez et al. explore low-cost surveying techniques using UAVs, emphasizing the affordability and accessibility of UAV technology for mapping and surveying applications [34]. Through case studies and demonstrations, the study showcases the potential of UAVs in democratizing surveying practices and expanding access to geospatial data collection methods.

Having analyzed all the research presented above, a methodology for our own research has been determined. All the studies describe various applications of UAVs for delineating object boundaries, monitoring them, and establishing protective zones. However, in each specific case, these methods will vary depending on the legislation of each particular country, so our research will differ from existing ones.

The advantages of using aerial imagery with UAVs for monitoring historical and cultural heritage sites, compared to other methods, include increased accuracy, cost-effectiveness, and reduced environmental impact. In terms of accuracy, UAVs equipped with high-resolution cameras can capture detailed imagery with precision, allowing for the accurate delineation of object boundaries and the monitoring of site conditions over time. Additionally, UAVs can access difficult-to-reach areas, providing comprehensive coverage of heritage sites, which may be challenging to survey using traditional methods. From a cost perspective, UAV-based aerial imaging offers significant savings compared to manned aircraft or satellite imagery. The operational costs of UAVs are generally lower, as they require less fuel and maintenance, making them a more cost-effective option for long-term monitoring and documentation of heritage sites. Furthermore, the use of UAVs for aerial imaging has minimal environmental impact compared to manned aircraft or ground-based surveys. UAVs produce fewer emissions and disturbance to wildlife, making them a more environmentally friendly option for heritage site monitoring. Additionally, UAVs can operate at lower altitudes, reducing the risk of interference with sensitive ecosystems or cultural landscapes.

The proposed research method is fundamentally not new and is applied by many scientists and practitioners who study historical and cultural heritage around the world. It is often used for monitoring extensive historical and cultural heritage sites using UAVs. Our proposals differ from others in the second part of processing the overall method. Specifically, in the design of object protection zones, various methods are adopted based on constantly changing legislation. This method allows for timely adjustments to the protective zones of objects in response to the rapidly changing surrounding infrastructure.

2. Study area

Two sites of historical and cultural heritage were chosen as cases of the research: the Church of the Holy Trinity of 1412 in Liuboml (including the adjacent territory) and the New Jewish Cemetery (Yanivskyi Cemetery) in Lviv.

2.1 Study area 1: Holy Trinity Church in Liuboml

The stone Gothic-style church was built by the Polish king Vladislav Jagiello in 1412. It was burned and was rebuilt repeatedly. Another circumference was added to it on the west side in 1731. The church has been Baroque since the 18th century. This is a one-nave brick building with one semicircular apse. The roof with high gable signature covers, the church, but covings were not remained. The main facade is accomplished with a two-level Baroque smooth outline gable with lateral volutes. Partially Renaissance portal was remained. The altar temple was oriented to the East. A miraculous image of Our Lady with Child, known as Our Lady of Liuboml, was the main sanctuary of the church. The icon was mentioned in the documents at first in 1750. There were five altars and eight-register organ in the church. The bell tower with three bells was built next to the church in 1764, and funded by the Volyn governor, Liuboml principal Antonina Zhevuska. The church stopped its activity in 1944. It suffered significant losses during 1945–1980: the copper tin from the roof was stolen; all burials in the dungeon of the church were ransacked; the narthex and lateral chapel (attached to the 500th church anniversary in 1912) were demounted; and the fresco of the crucifixion in a niche on the altar outside was destroyed. All the books and documents were burned. The organ and altar were broken and destroyed. After the independence of Ukraine; namely in 1992, the building was returned to the Liuboml Roman Catholic community, and in the feast day of Holy Trinity on June 14, 1992, the church sanctified by the Lutsk priest Ludwig Kamilevski.

The appearance of the church with the adjacent territory in 1934 is shown in **Figure 1** [35].

Figure 1. Photo of the church of the Holy Trinity in Liuboml in 1934.

Architectural Features

Architecturally, the Holy Trinity Church in Liuboml belongs to a neo-Gothic style with elements of Baroque. The building boasts impressive tall towers and a grand facade. The interior decoration is characterized by luxury and holds significant artistic potential.

Current State of the Object

At present, the Church of the Holy Trinity is undergoing restoration due to damage caused by time and natural factors, particularly affecting the fence and facade. Restoration is being carried out to preserve the historical value of this object.

The boundaries of aerial survey work for refining the historical boundaries of the site and the protective zone using GIS technologies are shown in **Figure 2**.

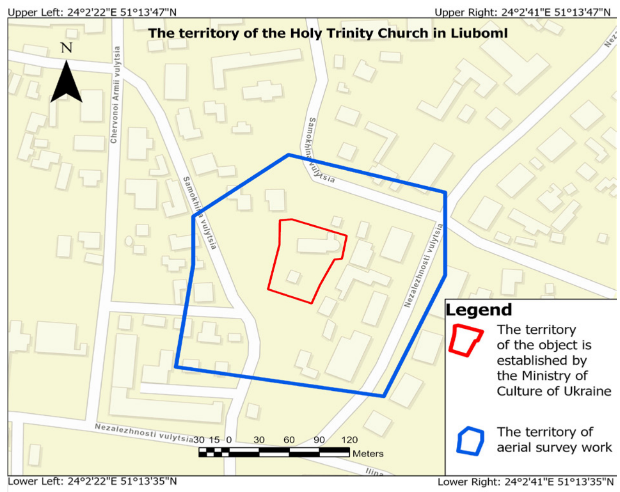

Figure 2. Outlined area of the territory designated for aerial survey work.

This site has significant relevance to our research due to its historical significance and role in the cultural heritage of the region. As the church is within the scope of our study, it is important to explore its history, architectural features, and current state to determine its impact on the surrounding environment and its relationship with adjacent cultural heritage sites.

The modern boundaries of the object set by the Ministry of Culture of Ukraine differ from its historical boundaries, requiring further research.

2.2 Study area 2: New Jewish Cemetery in Lviv

The New Jewish Cemetery was opened on August 24, 1855, 2 days after the closure of the old Lviv burial ground, which at that time was overflowing with burials due to the cholera epidemic. It is located on the Pylyhivsky Hills behind Kortumova hill near Yanivska Street (now Shevchenka Street).

In 1856, the New Cemetery Synagogue was built on the cemetery at the expense of the Jewish merchant Ephraim Viksel. In 1875, the Jewish community paved Pylyhivska Street (now V. Yeroshenka Street), which led to the cemetery from Yanivska Street.

After World War I and the November Pogrom of 1918, the Jewish community of Lviv established a grand monument on Kortumova Hill (between Eroshenko Street, Shevchenko Street, Tunnelska Street, and Warsaw Street) in honor of its victims. Around the monument, they created a memorial for Jewish soldiers who died between 1914 and 1918, consisting of 15 rows of graves, each containing no fewer than 23 burials.

During the World War I, the New Jewish Cemetery continued to function. The ruins of tombstones could be seen as early as the 50s of the 20th century.

In 1931-1932, the cemetery occupied an area of 25 morgens. In the middle, there was a main alley, from which smaller alleys branched off, along which graves were arranged in dense rows. On August 9, 1934, architect Norbert Glatstein completed the project for the fence of this cemetery.

At the beginning of the Nazi occupation, the New Jewish Cemetery continued to function for some time, as evidenced by the burial registration book (1941-1942). After the execution of members of the Lviv Judenrat in January 1943, the destruction of the cemetery began. The most valuable granite and marble monuments were removed from their pedestals and sent to Nazis after being reworked. Some of the slabs were used to pave strategic roads. In memory of the Jews who were annihilated in 1942-1943, an obelisk was erected.

In 1946, the Jewish community of Lviv erected a granite obelisk near the entrance of the cemetery (from the side of current Yeroshenka Street) at the mass grave. The grave contained the remains of Jews who were shot in 1942-1943 and the destroyed ancient burials, whose remains were gathered from the entire cemetery. To the right of the administrative building, a small annex was constructed and used as a pre-burial facility.

In 1962, due to the dissolution of the Lviv Jewish community, the administrations of the Jewish and Yaniv cemeteries (established in 1883) were merged. The territories of both cemeteries remained unchanged. The Jewish cemetery maintained its own field numbering system. During the communist rule, the land of the Jewish burial grounds was allocated to Christians by default under the guise of administrative consolidation.

Currently, three-quarters of the New Jewish Cemetery is occupied by Christian graves, which are located in the excavated Jewish burial sites. In the southern part of the cemetery, there are about a hundred Muslim graves. Jewish burials (after 1944) are concentrated in several fields near the main avenue. In the place where the memorial to Jewish soldiers used to be, garages were built in the early 1960s.

As of 1944, the interpretation of aerial images taken during the Nazi occupation of Lviv reveals the outline of a cemetery confirmed by a cadastral map from 1936 (**Figure 3**), which can be considered as the final version as authentic for inclusion in the register of monuments. There is a referencing to modern urban planning [35].

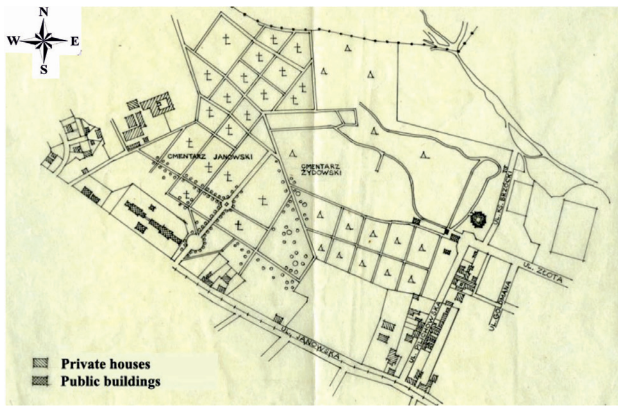

Figure 3. Plan of the Yaniv Cemetery in 1936 (with the historical boundaries of the New Jewish Cemetery).

After World War II, the Soviet authorities destroyed a part of the Jewish cemetery, constructing a thoroughfare called Yeroshenko Street with adjacent buildings through its territory. This included the site where a synagogue destroyed by the Nazis had once stood.

Architectural Features

The New Jewish Cemetery in Lviv is characterized by its ancient architecture, which includes classical Jewish elements and decorations. Among the most notable features are the ancient tombstones and intricate reliefs on the monuments.

Current State of the Object

As of today, the New Jewish Cemetery in Lviv is undergoing restoration. Due to years of neglect and the risk of losing historical landmarks, restoration and preservation efforts are being carried out to safeguard this cultural heritage.

The boundaries of the aerial survey operations, depicted in **Figure 4**, were overlaid on a fragment of the Lviv map. The total area covered by the aerial survey is 31.4 hectares. The aerial survey operations took place over several days, as the cemetery area was sufficiently large for aerial surveying using a copter-type UAV.

This object is of considerable importance to our study due to its historical and cultural significance. Since the New Jewish Cemetery in Lviv preserves many historical records and architectural details, studying it will help uncover its influence on the city's cultural landscape and enhance our understanding of the traditions and heritage of the Jewish community in Lviv.

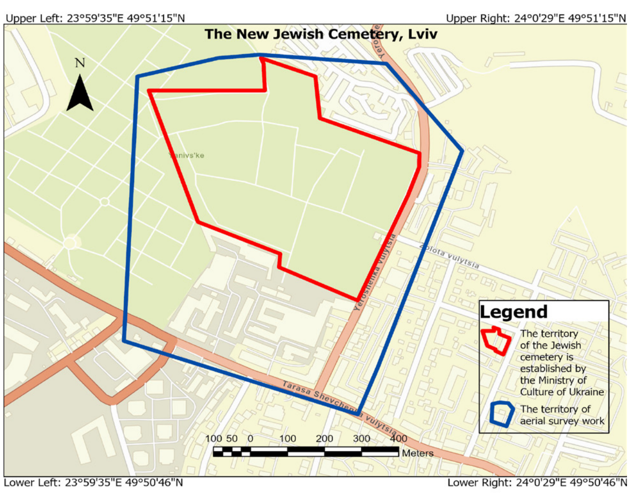

Figure 4. The boundaries of aerial survey works outlined on a fragment of Lviv map (*Bing Maps*).

For our research, the "New Jewish Cemetery" in Lviv and the Church of the Holy Trinity in Lyubomyl were deliberately chosen. Firstly, these are two different planar objects of historical and cultural heritage with different structures and histories, which allows us to assess the feasibility of applying the method to different objects. The main reason for choosing these particular objects is the discrepancy between the established boundaries of the objects by the Ministry of Culture of Ukraine and their historical boundaries, which is the subject of ongoing court hearings. Depending on the boundaries of the object, the protective zone will be adjusted, which will directly affect the objects and architectural structures located around them.

3. Materials and methods

The purpose of our research is to determine protective zones of land plots designated for historical and cultural purposes of various geometric shapes and historical boundaries using aerial imagery from Unmanned Aerial Vehicles (UAVs). This issue is currently very pressing in Ukraine, as rapid reforms are taking place in all ministries, including the Ministry of Culture. Legislation often changes while lawmakers seek the most effective forms of research, protection, conservation, or historical and cultural heritage objects. Consequently, there is a constant need for updated graphical documentation. Since research objects are located in tourist areas, the surrounding infrastructure is constantly changing, making updates using traditional surveying methods impractical due to the significant time required for execution. Additionally, financial considerations are significant. Again, updates to object territories are quite frequent, and from a financial perspective, using aerial imaging with UAVs for subsequent delineation of object boundaries and variations in protective zones is less costly. The task of this research was to perform aerial surveying from UAVs to create local orthophoto maps and establish historical boundaries of historical and cultural heritage objects, which may differ from officially approved ones, and to construct possible variants of protective zones.

The uniqueness of the research data lies in the fact that when using a known methodology for creating orthophoto maps with UAV data, we explore options for modeling protective zones based on different legislative norms over time, with the implementation of specific nuances. This can be beneficial not only for the territory of Ukraine but also for other countries undergoing reforms in this field.

3.1 Calculation of parameters for aerial survey operations

Although the majority of aerial survey calculations for unmanned aerial vehicles (UAVs) are now automated through flight planning software on the controller, verifying the accuracy and reliability of data for a specific scale of aerial imaging remains essential. This is because software can encounter errors, resulting in incomplete or incorrect results.

To calculate the parameters of aerial surveying, the following calculations need to be performed.

Firstly, the required flight altitude is calculated depending on the desired scale to be obtained. The flight altitude is calculated using equation (1) [36]:

$$H_{F.} = F_{C.} \times \mathrm{M}_{IM.} \tag{1}$$

where $H_{F.}$ serves as flight altitude, $F_{C.}$, camera focal length, and $\mathrm{M}_{IM.}$, scale of survey.

The next step involves determining the basis line in equations (2) and (3), which depends on the overlap of images along the *x-axis* and the scale of the survey [19,36].

$$b_{IM.} = l_x \times \frac{100\% - Px\%}{100\%} \tag{2}$$

$$B_x = b_{IM.} \times M_{IM.} \tag{3}$$

Where $b_{IM.}$ serves as the length of the baseline component, P_x, the length of the baseline component, B_x, the length of the baseline component on the ground, and $M_{IM.}$, the scale of the image.

Distances between routes are also calculated in equations (4) and (5), which depend on the overlap of the images along the axis and the scale of the survey [19].

$$d_y = l_y \times \frac{100\% - Py\%}{100\%} \tag{4}$$

$$D_y = d_y \times M_{IM} \tag{5}$$

Where d_y serves as the length of the baseline component along the *y-axis*, *Py*, the length of the baseline component along the *y-axis*; D_y, the length of the baseline component on the ground along the *y-axis*, and $M_{IM.}$, the scale of the image.

The number of images in a route is calculated using the equation (6):

$$n = \frac{A}{B\text{x}} + 3 \tag{6}$$

where *A* serves as the length of the longitudinal side of the survey, and B_x, basis line on the ground.

The number of routes is calculated using the equation (7):

$$N = \frac{C}{D_y} + 1 \tag{7}$$

where *C* serves as width of the survey area, and D_x, the distance between routes in terrain.

After these calculations, the total number of images obtained from the aerial survey can be determined in equation (8).

$$\sum_{\text{зн1.}} = n \times N \tag{8}$$

where *N* serves as the coefficient of increase in the number of aerial images due to various errors, and *n*, the number of flight routes.

The mileage for the survey in this case will be calculated using the following equation (9).

$$L_{\text{пк1.}} = N\ (\mathrm{A} + 2 = B_x) + C \tag{9}$$

And at the final stage, the basic vertical angle is calculated using the equation (10):

$$tg\lambda = \frac{B_x}{H_{F.}} \tag{10}$$

where $H_{F.}$ serves as flight altitude, and B_x, basis line on the ground.

3.2 Methodology for creating orthophotoplans to determine boundaries and protective zones of lands of historical and cultural purpose

Processing of aerial images, digitization of orthophoto plans, was carried out in Delta Digitals software.

Elevation marks were obtained by direct selection of DEM points obtained from the results of digital image processing in Autodesk Recap software.

Interpolation of contours is performed in Delta Digitals software based on selected points with 50cm intervals.

Topographic maps of the terrain at a scale of 1:500 were compiled based on the survey materials.

As input data for determining the protection zones of lands of historical and cultural purpose, the results of aerial surveying of these territories from various UAVs with subsequent creation of orthophoto plans and vectorization of objects to create 1:500 scale plans were chosen. Additional materials in the form of archival aerial images from manned aircraft and archival cartographic data were used to determine the historical boundaries of objects of historical and cultural heritage.

Considering that the boundaries of the land parcel for the church with the cadastral number 0723310100:01:000:1959 were entered in the coordinate system adopted on the territory of the Soviet countries in 1963 (SK 63), topographic and geodetic works were performed in the same coordinate system, with the Baltic height system.

Aerial surveying of the territory was conducted using a DJI Mavic 2 Pro unmanned aerial vehicle with the Pix4D Capture Android application [37]. Thanks to its 1-inch CMOS sensor with a resolution of 20 megapixels and a Hasselblad lens, the Mavic 2 Pro delivers high-quality images with high levels of detail and color accuracy. With an adjustable aperture from f/2.8 to f/11 and support for a 10-bit Dlog-M color profile, the Mavic 2 Pro allows for surveying in various lighting conditions and provides greater flexibility during post-processing. The three-axis gimbal stabilization system enables stable shots even during the aircraft's movement, which is crucial for obtaining clear and continuous images. With its sophisticated design and compact dimensions, the Mavic 2 Pro is easily transportable and quickly ready for flight anytime, anywhere. DJI offers a wide range of additional accessories and software that complement the capabilities of the Mavic 2 Pro, making it more versatile for various types of aerial imaging tasks.

The aerial survey took place on November 2, 2022. The surveying altitude was 70 meters, covering an area of 190 m × 187 m. The image overlap was 85% in the transverse direction and 77% in the longitudinal direction (**Figure 5**). The flight time was 8 minutes and 31 seconds. As a result, 163 georeferenced digital images were obtained.

As a coordinate framework, the points of the State Geodetic Network (SGN) were used to perform the work, and their coordinates were obtained in the coordinate systems SC63 and USC2000.

At these points, control measurements were conducted using the South S82 GNSS receiver in RTK mode. The GeoTerrace service of the Institute of Geodesy at the Lviv Polytechnic National University was used as the network of permanent GNSS stations. Using the GNSS receiver in mode Real-Time Kinematics (RTK), planimetric and altimetric coordinates of reference and control points were obtained, totaling 15 points. The errors in determining these coordinates are provided in **Table 1**.

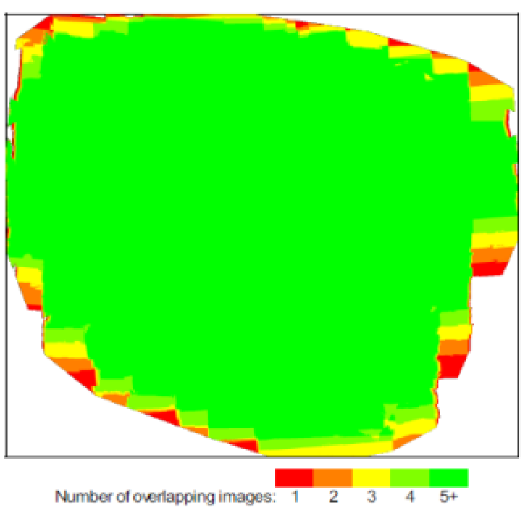

Figure 5. The overlap zone of the studied territory with aerial images.

Table 1. Localization accuracy per Ground Control Point (GCP) and mean errors in the three coordinate directions.

GCP Name	Accuracy XYZ (m)	Error X (m)	Error Y (m)	Error Z (m)	Projection Error (pixel)	Verified/Marked
1(3D)	0.02/0.02	0.010	–0.011	0.010	0.8	22/22
2(3D)	0.02/0.02	0.008	0.004	0.001	0.7	21/21
3(3D)	0.02/0.02	–0.004	–0.012	0.049	0.9	10/10
4(3D)	0.02/0.02	–0.021	0.016	–0.022	0.8	8/8
5(3D)	0.02/0.02	0.003	0.006	–0.007	0.7	13/13
6(3D)	0.02/0.02	0.004	–0.010	–0.016	0.9	16/16
7(3D)	0.02/0.02	0.006	0.006	0.005	0.8	19/19
8(3D)	0.02/0.02	–0.009	0.001	0.008	0.8	23/23
9(3D)	0.02/0.02	–0.005	0.009	–0.009	0.8	18/18
11(3D)	0.02/0.02	–0.006	0.009	0.013	0.7	8/8
12(3D)	0.02/0.02	0.016	–0.009	–0.000	0.7	15/15
14(3D)	0.02/0.02	0.004	–0.009	–0.013	0.7	10/10
15(3D)	0.02/0.02	–0.015	0.006	–0.014	0.8	12/12
Mean (m)		0.00	0.00	0.00		
Sigma (m)		0.01	0.01	0.02		
RMS Error (m)		0.01	0.01	0.02		

The processing of digital images was performed using Pix4D Mapper software. **Figure 6** shows the generated orthophoto and elevation map of the Holy Trinity Church area in Liuboml.

Since the DJI Mavic 2 Pro quadcopter was undergoing repairs at the time of the aerial survey work of the second research area, aerial imaging was performed using the DJI Phantom 3 Pro. This quadcopter also has excellent features and is equipped with a 1/2.3-inch CMOS sensor with a resolution of 12 megapixels and a fixed aperture f/2.8 lens. This allows for high-quality images with good detail and color accuracy. The Phantom 3 Pro has a stable shooting platform thanks to the built-in three-axis stabilization system. This enables smooth and stable shots even during the movement of the aircraft. The Phantom 3 Pro features a powerful remote control with the ability to transmit video in real-time to a mobile device or tablet. This allows the operator to control the drone and frame shots in real-time. With an intuitive and easy-to-use interface, the Phantom 3 Pro is suitable for both beginners and experienced users. It quickly sets up and is ready to fly, allowing

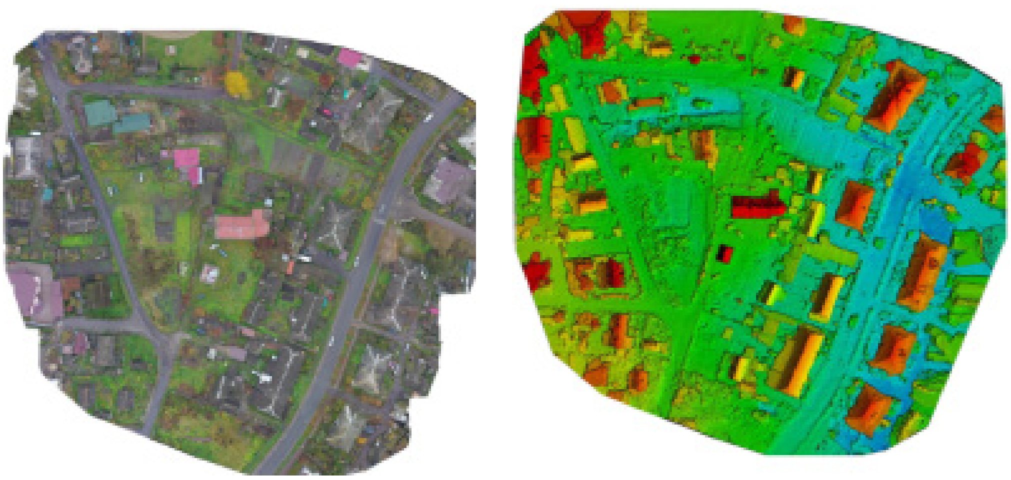

Figure 6. Generated orthophoto and elevation map of the Holy Trinity Church area in Liuboml.

for a quick start of surveying [38].

The survey altitude was 120 meters. The overlap of the images was 80% across and 50% along the flight path. As a result, 196 digital images were obtained. Aerial imaging was carried out along 11 routes. For the georeferencing of the images, 54 control points were used, distributed throughout the area of the aerial survey. The coordinates of the points were obtained using GNSS surveying with a South S82 receiver in RTK mode.

The processing of digital images was performed using Pix4D Mapper software. As a result, an orthophoto plan of the territory of the New Jewish Cemetery in Lviv was compiled at a scale of 1:500 (**Figure 7**).

Figure 7. Generated orthophotomap of the territory of the New Jewish Cemetery in Lviv.

According to documentary evidence, it is known that in the second half of the 20th century, a portion of the eastern boundary of the cemetery underwent reconstruction with the assistance of the Soviet authorities. This necessitated clarification of the territory for historical and cultural purposes. Just within the new boundaries, this object was registered as a monument of historical and cultural heritage. To determine the historical boundaries of the object, a fragment of an archival aerial image from 1944, obtained from the National Archives and Records Administration (NARA) [39], was additionally used (**Figure 8**) [17].

Figure 8. German archive aerial image from 1944 showing the territory of the New Jewish Cemetery in Lviv.

4. Results

4.1 Results for study area 1

In the first example with the Holy Trinity Church in Liuboml, the territory of the historical and cultural heritage site includes the church itself and the adjacent territory that has long been associated with a specific parish.

As a result of implementing the described methodology, an orthophoto plan of the research area was created, including the Church of the Holy Trinity and the adjacent territory.

Using the ArcGIS Pro geographic information system, historical boundaries of the historical and cultural heritage site were overlaid onto the orthophoto, transferred from archival cartographic materials.

Additionally, two variants of protective zones were established at a distance of 100 meters. Such distance of protective zones is determined by the dense development of the surrounding territory. The first protective zone, marked in blue, is built from the centroid of the historical territory of the object according to the new legislation of Ukraine. The second protective zone, known as the «clarifying protective zone», is built from the historical boundary of the object and marked in red. The second protective zone is established after the construction of the first protective zone and the inclusion of the object in the list of historical and cultural heritage sites of Ukraine (**Figure 9**).

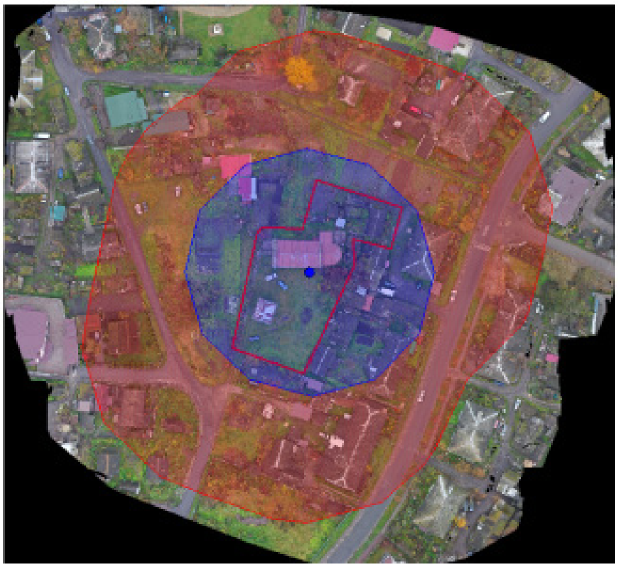

Figure 9. The boundary of the territory of the historical and cultural heritage site of the Holy Trinity Church in Lyubomyl, with the constructed buffer protection zones: marked in red from—the object's boundary; and marked in blue—from the centroid of the polygon.

4.2 Results for study area 2

In the case of the New Jewish Cemetery in Lviv, the situation is much more complex, as the territory currently listed in the register of historical and cultural heritage objects does not fully correspond to the historical boundaries of the cemetery. During World War II, as mentioned earlier, there was a known synagogue on the cemetery grounds that was destroyed by the Nazis. Additionally, a part of the cemetery's territory was destroyed by the Soviet authorities. Since reburial is impossible according to Jewish religious beliefs, some remains (those not covered by the construction of engineering structures) underneath modern infrastructure objects. By interpreting an archived Nazi aerial image from 1944 and using archival maps, it was possible to identify and display the affected areas on a topographic plan created based on the results of aerial surveys using unmanned aerial vehicles.

Determining the historical boundaries of objects of historical and cultural heritage plays an important role in establishing their protection zones and the boundaries of lands of historical and cultural purpose.

Figure 10 presents the result of the created orthophoto plan of the territory of the New Jewish Cemetery in Lviv, on which three variants of protective zones of the historical and cultural heritage site are overlaid.

Figure 10. The boundary of the territory of the cultural heritage site, the New Jewish Cemetery in Lviv with compiled buffer zones: red color—from the historical boundary of the site; blue color—from the actual boundary of the site recorded by the Ministry of Culture; purple color—from the centroid of the polygon.

The protective zone in the form of a buffer at a distance of 100 meters from the centroid of the object is shown in purple, which, as seen in **Figure 10**, does not even cover the territory of the object itself. This is one of the problems researchers encounter at some sites. Two boundaries of the New Jewish Cemetery in Lviv are overlaid on the orthophoto. The blue boundary indicates the boundary that was incorrectly imposed during the Soviet era and is currently the official boundary of the object legalized by the Ministry of Culture of Ukraine. The red boundary represents the historical boundary of the object based on archival cartographic materials and aerial photographs from 1944. As we can see, the territory inside the blue boundary is significantly smaller than the historical one. Protective buffer zones are also constructed around these two boundaries at a distance of 100 meters. The existing protective territory of the Jewish cemetery is indicated in blue, and the protective zone of the historical territory, which needs to be adjusted by the Ministry of Culture of Ukraine, is indicated in red. As seen in **Figure 10**, the actual protective zone is significantly larger than the legislatively established protective zone.

5. Discussions

The existing number of immovable cultural heritage objects in Ukraine currently on state registration is over 170,000 objects of cultural heritage. These are objects of cultural heritage entered into the State Register of Immovable Monuments of Ukraine; objects of cultural heritage recorded in accordance with the legislation that was in force before the enactment of this Law until the issue of inclusion (non-inclusion) of the object of cultural heritage in the State Register of Immovable Monuments of Ukraine is resolved, and objects of cultural heritage until the issue of their registration as monuments included in the List of Objects of Cultural Heritage and acquiring the legal status of newly discovered objects of cultural heritage.

It should be noted that the process of entering an object of cultural heritage into the State Register of Immovable Monuments of Ukraine is quite complex and time-consuming, complicated by the preparation of a significant amount of documents, sometimes duplicating each other, requiring significant financial expenditures for the production of mandatory documents.

The use of orthophoto plans form UAVs can be a significant tool for correcting boundaries and establishing protective zones of cultural heritage objects in Ukraine. The legislation of Ukraine, particularly the "On the Protection of Cultural Heritage" law, provides a legal framework for the identification and protection of these objects. Utilizing orthophoto plans, which provide detailed geographic information, enables precise inventorying of cultural heritage objects and their surroundings. Ukrainian legislation allows for the establishment of protective zones around cultural heritage objects to ensure their protection and preservation.

Literature sources indicate that orthophoto plans from UAVs can be used to assess the current state of territories where historical or cultural objects are located. This enables the detection of any environmental changes that may affect these objects and their surrounding areas. Literature sources also suggest the potential use of orthophoto plans for various projects in the field of cultural heritage preservation. This may include developing restoration or conservation plans for objects, as well as devising strategies for their future preservation.

Analyzing **Table 1** it can be observed that the localization accuracy per Ground Control Point (GCP) and the mean errors in the three coordinate directions are quite high. The root mean square errors in the x and y axes are almost identical, differing only by a fraction of a millimeter. Typically, the error value in the z axis is slightly larger, but in this case, the difference is not significant. As for the mean square error in height, it is also very low, possibly explained by the minimal height variations in the territory of the research objects.

This method, as expected, demonstrated its effectiveness in terms of the time required for creating the graphical basis and its updating. The only inconvenience in the case of the New Jewish Cemetery was the quite large area of imaging, which necessitated frequent battery changes when using our multirotor UAV. Therefore, in similar cases, it is recommended to assess weather conditions and the area of imaging in advance and, if possible, use fixed-wing UAVs for such areas and larger ones.

The study of the territory of the Church of the Holy Trinity in Lyubomyl is crucial in terms of the tourist attractiveness of this place. Orthophoto plans in the form of booklets will allow tourists to better orient themselves and see what the boundary of the object was in the past. The research of the New Jewish Cemetery in Lviv was conducted in collaboration with the Jewish community of the town of Turey Zagav and is extremely important for preserving the identity of Jews who, before World War II, were numerous in Lviv.

The scientific novelty of the topic lies in the utilization of orthophoto maps generated from Unmanned Aerial Vehicle (UAV) aerial images to facilitate the monitoring and preservation of historical and cultural heritage sites. This approach represents an innovative fusion of modern UAV technology with heritage conservation efforts, offering a non-intrusive and highly detailed method for documenting and analyzing heritage lands. By employing orthophoto maps derived from UAV imagery, researchers can achieve unprecedented levels of accuracy and resolution in capturing intricate details of heritage sites, including architectural features, landscape characteristics, and spatial relationships. Moreover, the use of UAVs enables frequent and cost-effective data collection, allowing for dynamic monitoring of changes in heritage lands over time. This interdisciplinary approach harnesses the power of remote sensing, Geographic Information Systems (GIS), and heritage conservation methodologies to enhance the documentation, management, and protection of cultural treasures for future generations.

In addition, all possible options for establishing protective zones around historical and cultural heritage sites have been considered for the first time in accordance with both old and new laws of Ukraine. According to the old law, protective zones are established from the boundary of the object to a specified distance. According to the new law, a protective zone is established around the centroid of the object up to a distance of 300 meters, depending on the density of development around it.

6. Conclusions

As a result of completing the assigned task, aerial surveys were carried out using Unmanned Aerial Vehicles of the copter type, namely DJI Mavic 2 Pro and DJI Phantom 3 Pro. Orthophotoplans were generated and further vectorized at a scale of 1:500 for two research areas of immovable objects of historical and cultural heritage with varying shapes and sizes: the Holy Trinity Church in Liuboml and the New Jewish Cemetery in Lviv.

The boundaries of the object of historical and cultural heritage registered with the Ministry of Culture of Ukraine, when these objects were added to the corresponding list, were drawn on the created cartographic materials, as well as orthophoto plans. In the case of the New Jewish Cemetery in Lviv, the historical boundary of the object, part of which was destroyed during the Nazi and Soviet occupation, was also determined using archival aerial images from the World War II and maps. The historical boundary is also drawn to determine how this area is consistent with the protection zone of the object established today.

Protective buffer zones for historical and cultural heritage objects have been constructed according to both old and new recommendations in Ukraine. These zones are measured from the established historical boundary of the object and from the centroid of planar objects. For the buffer zone measured from the centroid, construction is allowed up to a maximum of 300 meters for undeveloped areas and to a negotiated distance for developed areas, taking into account the maximum protective zone of 300 meters as a reference point.

One of the urgent tasks of reforming the field of cultural heritage protection, which is one of the government's priorities in the cultural sphere, is to change approaches to understanding the cultural heritage of the state as a whole, as well as reforming the registration of immovable cultural heritage. In this context, a necessary step is the formalization and digitization of standardized processes for accounting cultural heritage, the implementation of which in the field of immovable cultural heritage began in 2017 and was completed in 2018.

Since the process of reforming the Ministry of Culture in Ukraine is still ongoing, legislative restrictions on protective zones of historical and cultural heritage objects are constantly changing. Earlier, the protective zone looked like a buffer around the object's boundary by 100 m for undeveloped territory and decreased depending on the development. There were constant problems determining the final boundaries of planar objects of historical and cultural heritage, as the territories of historical boundaries often already belonged to private property. In this regard, as well as private objects that fell into the protective zone, and construction was prohibited on their territory, constant legal processes were taking place, dragging on for years. The inclusion of objects in the list of historical and cultural heritage was significantly delayed.

Due to the technical capabilities of modern UAVs, obtaining orthophoto plans with high detail is becoming increasingly accessible. This allows for more precise and efficient work in correcting boundaries and establishing protective zones of cultural heritage objects in accordance with legal requirements and high standards of professional practice.

In the future, there are plans to integrate the research data into the overall geographic information system of the plane objects of cultural heritage in Ukraine, which is currently in the design and development stage.

Author contributions

Conceptualization: B.C.; methodology development: A.M.; writing—original draft: S.R.; writing—review and editing: L.B.

Conflict of Interest

The authors declare no conflict of interest.

Data Availability Statement

The original contributions presented in the study are included in the article/supplementary material, further inquiries can be directed to the corresponding author(s).

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