Polish Cartographical Review
Vol. 54, 2022, pp. 123–142
DOI: 10.2478/pcr-2022-0009
Received: 24.08.2022
Accepted: 24.10.2022

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The Orthophotomap of Lublin 1944: from *Luftwaffe* photographs to map application – idea, methods, contemporary challenges of processing and publishing archival aerial photographs

Abstract. The origins of aerial photography can be traced back to the second half of the 19th century, and periods of World Wars contributed to the development of techniques for developing and disseminating aerial photographs for military purposes. In the literature, we find descriptions of the Polish Military Geographical Institute's (WIG) use of aerial photography to update topographic maps of nearly 40% of the country's area at the time. Unfortunately, the fate of the pre-war collection of photographs is difficult to establish. Given this, the aerial photographs from the period of the Second World War (German and Allied) constitute the oldest possible complete and consistent photographic documentation of Poland. The series of German prints *(373-GXPRINTS)* collected at the *National Archives and Records Administration* in College Park (NARA, USA) are maintained according to the most liberal policy on access and further use. At the same time, the organisation of the NARA archive and the extent to which the collection has been digitised (over one million images) leave a deficiency, and searching for images requires knowledge, methods and experience.

In 2020–2021, the Department of Geomatics and Cartography of the Maria Curie-Skłodowska University implemented the project *Development of the Ortophotomap of Lublin 1939–1945* (NCN, Miniatura 4.0. No. 2020/04/X/HS4/00382). The result of the project is a dedicated web portal https://ortolub.umcs.pl, consisting of a digital repository of aerial images, a map application and standardised GIS raster data services. The author believes this is a unique source base, with unprecedented detail. The publication of the project results under the Creative Commons CC-BY-SA 4.0 licence is intended to foster the widest possible use of wartime aerial images in scientific research and popularisation activities.

The process of developing a historical orthophotomap, as presented in the article, is universal and can be repeated on any set of aerial photographs. At the same time, development work is needed to automate the operations as fully as possible. In conclusion, current challenges and prospects for the development of historical orthophotomaps of national coverage are indicated.

Keywords: aerial photography, NARA, *Luftwaffe*, Second World War, historical orthophotomaps, geoportal, historical GIS, Lublin

Foreword

The author of this article aims to present the research proceedings and to summarise the experience resulting from the project *Development of the Ortophotomap of Lublin 1939–1945*, carried out in the Department of Geomatics and Cartography within the framework of the grant of the National Science Centre – Miniatura 4.0. no. 2020/04/X/HS4/00382.

The following article consists of six chapters organised in a three-part structure. Chapters 1–2 are intended by the author to be introductory: chapter 1 outlines the historical background to the development of aerial photography, while chapter 2 is devoted to aerial photography from the Second World War period. Chapter 3 is the essential, analytical part of the study. The following subchapters describe the process of realisation of the project *Development of the*

Ortophotomap of Lublin 1939–1945. Thanks to NCN funding, German aerial photographs of Lublin were acquired from NARA and processed (subchapter 3.1). These were then subjected to several digital processing procedures, georeferencing (3.2) and transformed into raster data services (3.3). The extent of metadata (3.4) and the various forms of publication of the collection (3.5) are described. Chapters 4 and 5 represent discussion. In chapter 4 various examples of the use of archival aerial photographs in scientific research in Poland are presented. Chapter 5 indicates the importance of the historical orthophotomap of Lublin for the year 1944 for the study of the city space. In conclusion (chapter 6), the universal nature of the research procedure is indicated. The main challenges and prospects for the development of historical orthophotomaps of national scope were also outlined.

Fig. 1. *Paris, Arc de Triomphe*, one of the first photographs taken from a balloon by Felix Tournachon. Source: Archives Nationales de France

1. Introduction

1.1. The beginnings of aerial photography

The origins of aerial photography can be traced back to the 19th century and are directly linked to the development of two technological fields: photography and aviation. The first balloon flight was carried out in 1709 by the Portuguese Bartolomeu de Gusmão, but it was not until the 1780s that a design was developed in France that allowed repeated flights of helium-filled balloons. 1794, June 26, during the Battle of Fleurs, the French Army first used a balloon for reconnaissance purposes, dropping short reports on enemy troop movements to the ground. In 1853, from a balloon at a height of 200 fathoms (approx. 430 m), Adam Lerue and Julian Cegliński made an axonometric projection of Warsaw.

The first documented "aerial" photograph of the Earth's surface was taken in 1858 by Gaspard Felix Tournachon (known as "Nadar") during a balloon flight over Paris (fig. 1). On 1865, July 30, Konrad Brandel took a series of oblique photographs of Warsaw from a low-flying balloon. In 1882, British meteorologist E. D. Archibald took a photograph using a kite and a delayed self-timer shutter. On 1882, May 29, Cecil Shaboldt took the first vertical aerial photograph from the camera placed in the bottom of a balloon basket (fig. 2). The invention of the aeroplane (Wright brothers – 1903) marked the beginning of the rapid development of aerial photography (Olędzki, 2009; Różycki et al., 2020a; Vogler, 2020).

The period of the First World War was a watershed in the development of aerial reconnaissance (aircraft and balloons). The acquisition of up-to-date and accurate situational information determined the tactical advantage and was widely used on all European fronts. The number of aerial photographs taken by Germany is estimated at several thousand per day (Stichelbaut, 2011; Stichelbaut et al., 2017; Vogler, 2020). The oldest known and surviving aerial photograph of the present area of Poland was probably taken on 5th February 1915 by the Austrian *10th Fliegerkompanie* (FL.K) from a Lohner C aircraft. It covers the area around Gorlice all covered in snow (Kycko, 2011; Olędzki, 2009, fig. 3).

1.2. Aerial photography in the Second Polish Republic

In Poland during the Interwar Period, aerial photographs were taken to delimit the eastern border of the State (in the years 1921–1923). Aerial photographic work was dealt with by the Photogrammetric Division of the Military Geo-

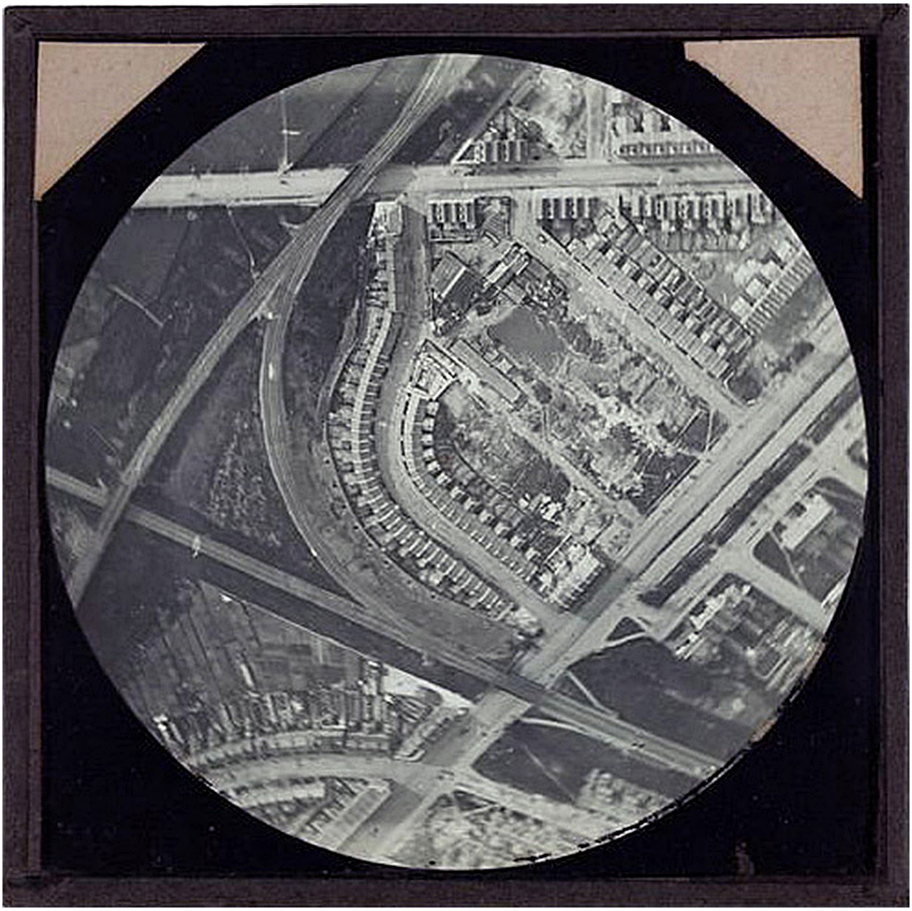

Fig. 2. *Stamford Hill, Stonebridge Road & Tottenham and Hampstead Junction Railway* – first vertical aerial photograph, Cecil Shadbolt, 610m, 29 May 1882. Source: Wikimedia Commons, from the collections of Historicengland.org.uk

graphical Institute (hereinafter: WIG) in cooperation with the 1st Aviation Regiment, and the number of photographs taken is estimated by Krassowski (1973, pp. 30, 60) estimates at several thousand.

"The work on the measurement of the Polish-Soviet border deserves special attention (leaving aside its other values) because it was the first work in Poland on such a large scale, bringing very important experiences for the young photogrammetric personnel and the aviators" (Krassowski, 1973, p. 60).

Based on a series of photographs, the Photogrammetric Division of WIG produced – in single-image technique – standardised, "straightened" photomaps at a scale of 1:10,000, using old transducers left behind by the German army. The 1:10,000 photomaps were the basis for further field measurements, including: the survey of training camps (1923–1925), the triangulation of the Polish Coast (1925–1926), as well as for the ongoing updating of other maps. In the years 1927–1931, the Independent Photogrammetric Division underwent modernisation, as part of which world-class equipment was purchased: transducers, autographs, and modern aerial cameras, enabling tasks to be carried out on a national scale, including stereoscopic photographs. In 1930, parallel to the WIG, an Aerophotogrammetric Division – FOTOLOT –

Fig. 3. *Gorlice, 5th February 1915,* 10 FL.K. Source: Kriegsarchiv – Österreichisches Staatsarchiv [in:] Olędzki, 2009

was established in the civil aviation division "LOT" (Krassowski, 1973; Olędzki, 2009; Różycki et al., 2020a). The main scientific centres involved in aerial photogrammetry were the Lwów and Warsaw Polytechnics. WIG, LOT and the scientific institutions cooperated closely in terms of training, exchange of experience and division of work. Joint work included the development of a photogrammetric map of the Tatra Mountains and Polar expeditions to Spitsbergen and Greenland. An example of world stature was the use of balloon photographs of the discovery of an archaeological sensation in Biskupin in 1934 (Ławecka, 2009). From 1933, aerial photographs were used *en masse* to update topographic maps:

"...the topographer would receive a print of the old map to be checked at a scale of 1:25 000 and a set of aerial photographs covering the map area at a scale of approximately 1:17 000, measuring 18 × 18 cm" (Krassowski, 1973, p. 65).

By 1939, the WIG had taken aerial photographs for 150,000 km^2, i.e. about 40% of the country's area at that time – this is consistent with the findings of the update of the 1:25,000 detailed map, including the "partially compiled" sheets (Krassowski, 1973; Kuna, 2018). Unfortunately, the wartime and post-war fate of the collection of the WIG Photogrammetric Division is today, from the perspective of civilian researchers, very difficult to determine.

Single aerial photographs, vertical and oblique, from 1918–1939 (and older) are increasingly "found" in historical and regional publications, auctions and online forums (cf. fig. 7). The largest publicly accessible collections are Fotopolska.eu and Wikimedia Commons (2022). An important part of organising the resources of Fotopolska.eu (2022) and Wikimedia is geographical tagging, i.e. the tagging of photographed towns and objects, which enables the initial identification of photographs based on queries to the database or an interactive map. Unfortunately, as these are community collections, they are heterogeneous in terms of the origin of the images, source description, quality of the scans and re-use rights. For this reason, it is difficult to unequivocally assess pre-war aerial photographs as material for systematic research work.

2. The Second World War aerial photographs

The Second World War was a period of rapid development for aviation, and indirectly for aerial photography. The number of photographs taken between 1939 and 1945 by all sides in the conflict is estimated at 50 million. In addition to the “mass” taking of increasingly better quality photographs, the process of photointerpretation and the production of derivative products also improved. Różycki et al. (2020a, p. 7) report that nearly 80% of the German photo collection was deliberately destroyed for fear of being seized by the Allies. Indeed, in parallel to their aerial reconnaissance within the *Joint Air Reconnaissance Intelligence Centre* (JARIC), Allied military intelligence conducted special operations to acquire German photographs (Vogler, 2020).

In the US (*National Archives and Records Administration* – NARA in College Park) and UK (*National Collection of Aerial Photographs* – NCAP in Edinburgh) archives, a total of nearly 10 million aerial photographs from the Second World War have survived to the present day, including more than one million German photographs (Cowley et al., 2013; Różycki et al., 2020a). Several thousand aerial photographs are made available in the digital repository of the Herder Institute in Marburg. Vogler (2020, pp. 539–558, 587–591) lists many institutions with smaller collections of aerial photographs. The storage locations and state of preservation of the USSR collections (as well as the photographs captured by the Russians on the Germans and the Polish) are difficult to determine (Różycki et al., 2020a; Vogler, 2020).

Both NCAP (2022) and the Herder Institute (2022) maintain digital repositories of aerial photographs, allowing thumbnails of scanned images to be viewed. Interactive maps showing the location of the images are an important feature. The maps, based on OpenStreetMap, have an interesting feature of automatic aggregation of point-described geotags into circles representing the number of images in a given area – this is quite a convenient solution to the problem of uneven distribution of images and preserving the readability of the map regardless of the scale of the display. The shortcoming remains the cost of acquisition and further dissemination in publications, media and the Internet. NCAP’s licensing terms are quite complicated, with amounts ranging from £16.50 to £45.00 depending on the document format and from £5.50 to £429.00 depending on the form of redistribution. At the Herder Institute, these are in the order of €20 to €25 per scan and €30 to €100 for the rights to further use. From a Polish research perspective, these are prohibitive prices.

The situation is quite different in the US (NARA, 2022a). All collections declassified and transferred by the CIA to the National Archives are available for inspection free of charge and without any restrictions on further use. The greater difficulty lies in searching through the vast collections and accessing them themselves. The National Archives Catalog (NARA, 2022b) holds more than 200,000 archive units containing nearly 3 million Allied photographs and nearly 60,000 rolls of film. More than 50,000 Allied photographs from Assembly *373-AERIALFILM* (NARA, 2022c) are available online as scans (also downloadable, unfortunately mostly of poor quality).[1] More than 1.2 million German paper prints have been collected in the *373-GXPRINTS* (*German Flown Aerial Photographs, 1939–1945*) ensemble (NARA, 2022e). Of the German photographs, more than 22,000 are included in the digital catalogue, of which nearly 15,000 are available online as scans − downloadable for free and in vastly improved quality.[2] However, this is still just over 1% of the *Luftwaffe* photo collection.

2.1. Searching for *Luftwaffe* images in NARA

The *373-GXPRINTS* series collections are organised by series number dependent on the locations where the collection was acquired by Allied intelligence units, making the individual boxes identify the origin of the collection rather than its thematic content (Rożycki et al., 2020a, p. 60; Vogler, 2020). It is quite cumbersome and difficult to dissect. For example, the images of the Katyń Forest available on the archive’s website come from the GX 3707, GX 4257 and GX 4344 series, among others. An important “guide” in the context of finding specific locations is the *373-FILMOVERLAYS* series, which contains a geographical index of German images (NARA, 2022d). The geographical index is maintained in a 1×1 degree mesh

[1] Mainly GIF format, 8-bit, 72 dpi, although also JPG, 24-bit, 300 dpi.

[2] Mainly JPG format, 8-bit or 24-bit, 300 dpi, depending on the format of the photograph it is between 3,000 and 5,000 pixels per edge.

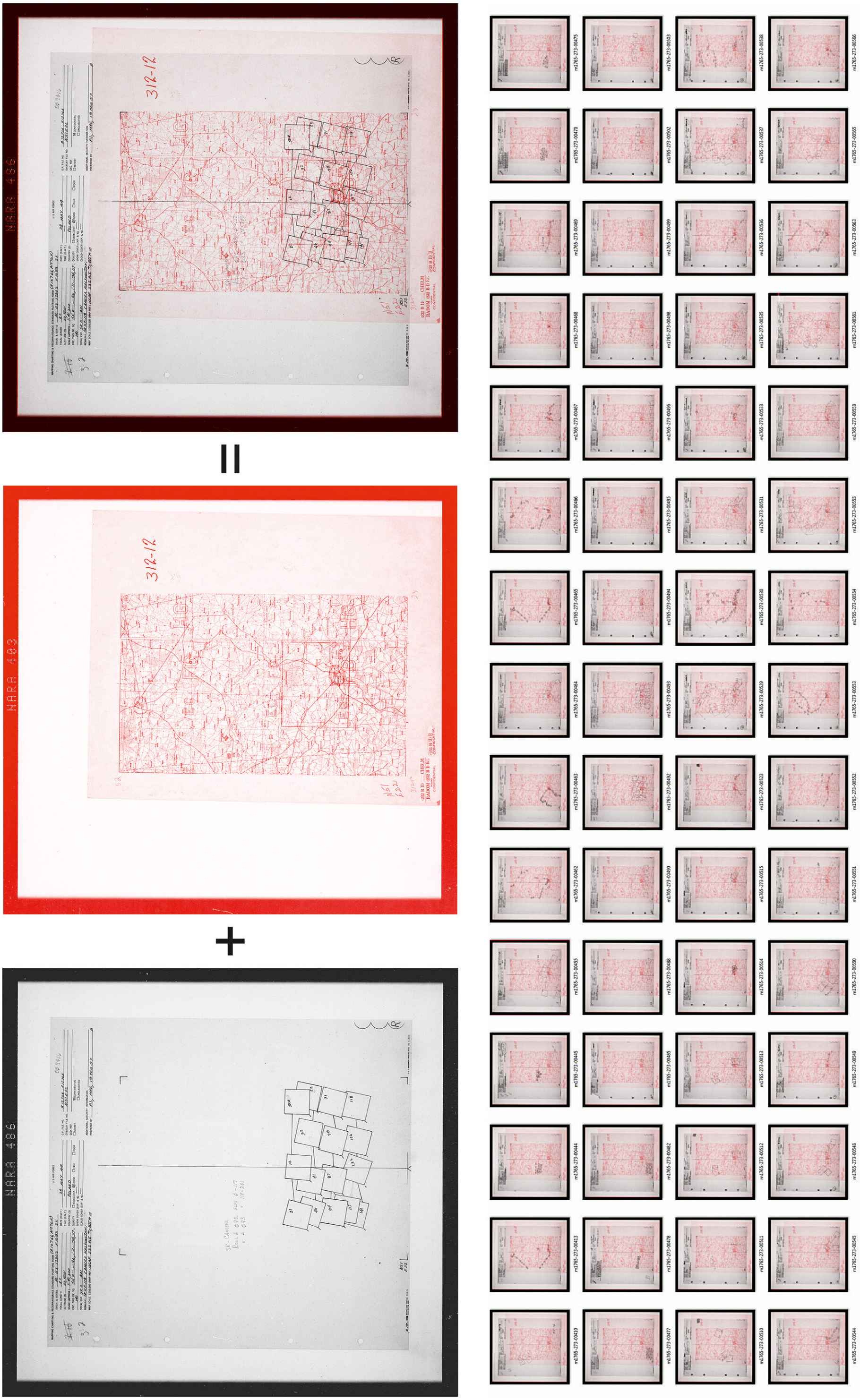

Fig. 4. NARA analogue index for mesh 51N022E of map 1:250,000. Top – superimposition of film coverage of images dated 25th May 1944 in colour separation technique, 19% of the original size; bottom – batch processing effect on the entire collection. Own compilation based on the NARA collection

(e.g. 51N022E), in the form of dozens to hundreds of transparencies (oleats) with a drawing of the ranges of the individual images (Vogler, 2020). A single film usually depicts a single flight, labelled with the date (often daily), lens parameters, average flight altitude, the approximate scale of the images and an indication of the quality/readability of the print. In the archive's readers room, it is possible to directly overlay the oleat onto an attached 1:250,000 map and read the extent of the photograph in the appropriate topographic context. In a digital environment, scanned oleats can be superimposed on a map scan (or vice versa) using transparency, different types of pixel blending or colour separation (fig. 4 – left). Due to the identical format of the 1:250,000 map matrix and the film overlays, using digital processing software, it is possible to perform batch processing to automate work on the entire film folder for a single-stage mesh (fig. 4 – right).[3] Note that the extents of the individual images plotted on the film are only approximations. It is usually possible to get an idea of which images are worth acquiring by adjusting the material in this way.

The cost of scanning paper prints outsourced to archive staff is in the range of $20–25, while during an in-person visit it is possible to bring your scanner and scan prints for $0.25 apiece – just fly to Washington![4] Of course, there are some limitations, according to Różycki et al. (2020a, p. 62):

"Individual researchers cannot scan the negatives of the Allied photographs themselves, but only view them [...]. The scanning of Allied photographs is authorised by the Archives by private companies, which perform such services for a fee...".

The restriction does not apply to paper prints; these can be scanned independently. In conclusion, the conditions for access, acquisition and use of collections at NARA are much more liberal than those at NCAP and the Herder Institute, but the search for relevant material locally requires skill and it is worthwhile to enlist the help of experienced people to do so.

[3] In Adobe Photoshop CS6, this is the function "automate" → "batch sequence".

[4] "Self-service scan – $0.25 per scan". It is reported by those doing the searches that when scanning with their equipment this fee is not charged.

3. Historic Orthophotomap of Lublin project

The project *Development of the Ortophotomap of Lublin 1939–1945* was planned as the basic research. The main objective was to acquire digital copies of aerial photographs from NARA in the form of high-quality scans and subject them to a series of editing procedures leading to the production of a historical orthophotomap and publication of the layer as a spatial data service.

3.1. Acquisition of digital copies

As part of the preliminary work, an inventory was made of aerial photographs made available on the Fotopolska portal. Nearly 200 photos tagged with the names of Lublin and neighbouring towns were found on the site. The downloaded thumbnail images (matrixes of approx. 570 × 550 pixels), were subjected to a cursory calibration (4 points, perspective transformation), which made it possible to create a spatial index of the photos in vector form. During this stage of the work, the biggest concern was to obtain full coverage of the present-day city space with the wartime photographs. Any shortcomings would have been a significant drawback for the project, and COVID-19 restrictions prevented the completion of the search during the funding period (October 2020 – October 2021). The development of the index in vector form resolved doubts about the completeness of the study and enabled the exact number of images required for the project to be determined. All 104 aerial photographs required for the project were digitally archived in the Fotopolska.eu user repository.

3.2. Processing of digital copies

The scans of the aerial photographs were subjected to a series of digital processing in the Adobe Photoshop CS6 graphics environment. Preprocessing included, among other things, the removal of marginalia, background stamps, captions and other elements covering the content of the photo. The marginal areas characterised by a large lenticular distortion were cropped and a tonal correction of the

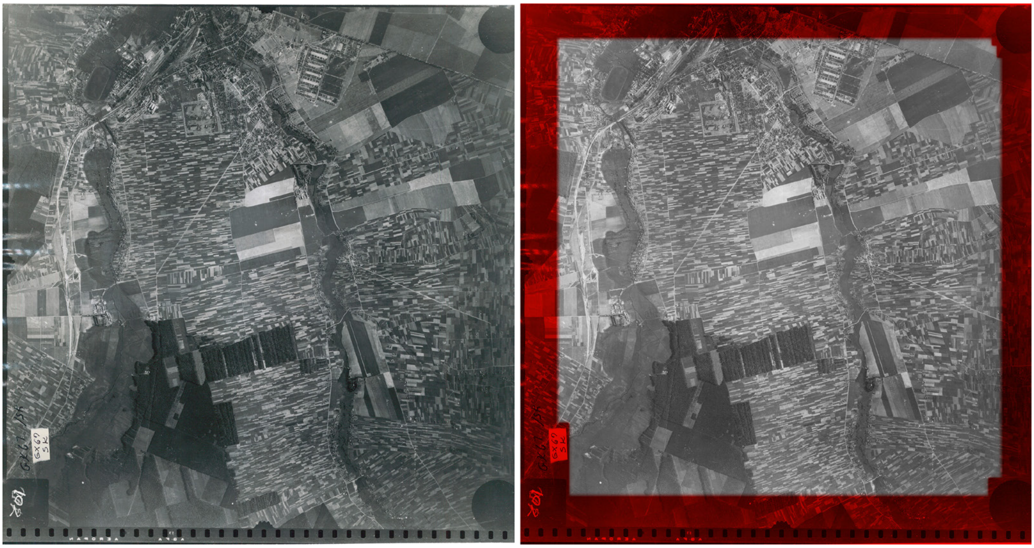

Fig. 5. German aerial photograph from 1944 *Lublin – Dziesiąta, Głusk, Majdanek*. On the left – the original scan, on the right: the photo after graphic processing – the area marked in red has been converted to an "alpha" transparency channel, 23% of the original size. Compiled images of the NARA collection

images was performed (fig. 5). In the course of the work, batch sequence schemes were developed to automate repetitive operations, e.g. colour-based pixel selection, masking with the "alpha" transparency channel, autocorrection of contrast and tone. Of course, the results of the automated work were not always satisfactory, and some of the images required individual processing.

Subsequently, using the functions available in QGIS Desktop 3.16. and Esri ArcMap 10.8.1, interpretation and georeferencing of the photographs to contemporary GUGiK reference data in the 1992 system (BDOT10k, orthophotomap, other auxiliary materials) was performed. From the point of view of geometry, an aerial photo (like any photo) is a kind of central projection mapping the registered objects on a plane

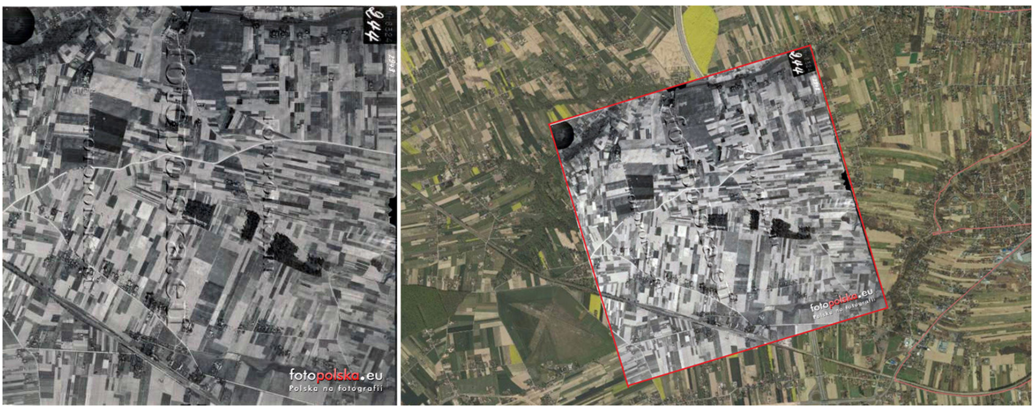

Fig. 6. Left − German aerial photograph from 1944, Kozubszczyzna near Lublin, thumbnail from Fotopolska.eu Right − photograph after initial calibration. The regular, almost square area of the photo's coverage suggests that the camera's tilt was very low when the photo was taken. Own compilation based on the collection of Fotopolska.eu

(photographic film, digital matrix). Due to the nature of the projection, photographs are characterised by a set of linear and directional distortions caused by the tilt of the photograph and the prominence of the terrain. In the case of vertical photographs (fig. 6), the main point is at the same time the focal point of the photograph (directly under the camera), projected perpendicularly to the surface of the film (orthogonal projection). The photograph covers the terrain in a regular form (close to square) and has a limited range. The lines of equal distance are arranged in a circular manner around the main point, the displacements due to ground prominence are negligible. The scale of an aerial photograph can be determined along any straight line and is relatively easy to calculate. Calibration of the photo can be performed using a linear (affine) transformation and 4–5 control points.

In the case of oblique images (fig. 7), the scale is varied over the surface of the entire image. The focal point of the image is offset from the projection point of the camera's position on the Earth's surface, and the extent of the terrain covered by the image has the character of a trapezium (image inclined in one axis) or an irregular quadrilateral (image inclined in two axes). In the case of photos with a very high tilt, the projection point of the camera position is outside the frame and the extent of the photo may have an open character (when the horizon is visible in the photo, the edge of the photo escapes to infinity). Calculating the scale of the photo and removing the deformation is significantly difficult. Calibrating tilted photos requires non-linear transformation methods such as perspective transformations, 2nd- and 3rd-degree polynomial transformations or folding transformations (TPS/adjust, spline). Depending on the type of transformation, the minimum number of control points necessary for the transformation varies between 6 and 16. A larger number of points results in greater averaging of local distortions and allows for better individual assessment of the position of individual points.

In addition to factors resulting from the nature of the terrain and the angle of the camera, the technical parameters of the equipment also contribute to the deformation of the images: the type of lens used, the focal length of the lens, and the size of the sensor. One of the effects resulting from equipment imperfections is the so-called lens distortion, i.e. deformation and loss of sharpness of objects located in the peripheral part, close to the edge of the photo. The last elements influencing the usability of the photographs and the possibility of their use as background material are atmospheric factors during their taking: the occurrence of clouds, windy weather causing vegetation to move, water ripples and the passage of time: fading of the film, scratches, dust (Ciołkosz & Kęsik, 1969; Ciołkosz & Miszalski, 1972).

The scanning quality of a photographic print can be assessed according to the use of printing standards: a 300 dpi scan captures all the details of a photograph in moderate quality, whereas a 600 dpi scan captures all the details

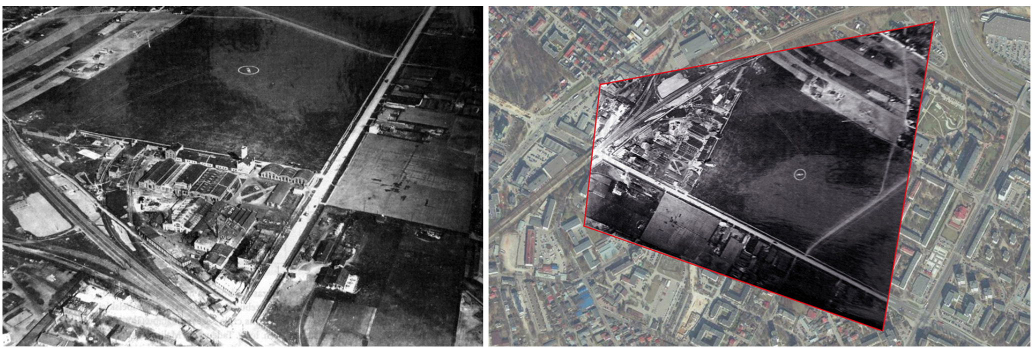

Fig. 7. Left − aerial photograph from 1930–1935, the E. Plage and T. Laśkiewicz's Aircraft Factory in Lublin and the adjacent aerial field. Right – photograph after calibration. The irregular, trapezoidal area of the photo's coverage is caused by the high tilt of the camera during the taking of the photo. Own compilation based on the collection of Fotopolska.eu

of a photograph in high quality. Scans made directly on photographic film require significantly better scanning parameters. Depending on the type of scanning device and the size of the film, photo scans at 1,200 and 2,400 dpi are the most common. The scan resolution influences the pixel size, which, after calibration, can be calculated and expressed in real metres as a spatial resolution, e.g. 0.1 × 0.1 m (pixel size of a high-resolution orthophotomap GUGiK).

Large area → high flight altitude → small reference scale → low level of detail → high calibration error in real metres (several to tens of metres)
Small area → low flight altitude → large reference scale → high level of detail → low calibration error in real metres (from several centimetres to a few metres)

The orthorectification and mosaicing (stitching) of aerial photographs into a professional orthophotomap is a rather complex process requiring the consideration of many technical factors, which are difficult to fulfil in the case of archival photographs (Mirończuk & Poławski, 2015; Różycki et al., 2020a). An important element affecting the quality of orthorectification is the mutual coverage of the images (vertical and horizontal), expressed by the percentage of the common area of following images (stereo pairs). In the case of the majority of acquired image series, the mutual coverage is preserved only in one line of flight (e.g. W–E) and does not exceed 30%. It was not possible to develop a true orthophotomap in full compliance with the principles of orthogonal projection. As a result, georeferencing operations were performed in the GIS environment using the single-image technique (cf. chapter 1.2) – analogous to the work with early topographic maps (Kuna, 2015).

Table 1. Interpretation of the estimation error against the offset value on the analogue material

Size of error at the scale of the reference map [mm]	Assessment of point matching (pre-1950 material)
< 0.10	Excellent
0.10–0.25	Very good
0.25–0.50	Good
0.50–1.00	Medium
1.00–2.00	Bad (to be checked)
> 2.00	Very bad (to be removed)

In simple GIS use, attention should be paid primarily to image size (area covered), scale (understood as the level of detail concerning the scale of a standard reference map) and the quality and resolution of the scan. The correctness of the calibration of aerial photographs can be assessed according to the criteria for calibrating reference maps at a similar scale (tab. 1). The actual spatial offset expressed in units of the coordinate system should be recalculated according to the scale of the reference map and compared with the eye's perception values:

$$k = \frac{\text{estimation error [m] * 1,000 [m to mm conversion]}}{\text{photo or map scale denominator}}$$

Note that the proposed values are not an absolute criterion for qualifying or rejecting a control point – they are a guideline for assessing the correctness of the fit, while the decision should depend on visual inspection.[5] Examples of georeferencing an image using the first-degree polynomial, perspective transformation and folding methods are shown in fig. 8. The criteria for selecting control points are described in table 2.

3.3. Preparation of raster data services

After being carefully arranged, the photos were mosaiced (stitched), i.e. the images were combined to form a large, uniform orthophotomap file. The aim was to fill the space of the city with photos at the largest possible scale (approx. 1:10,000), but this was not possible everywhere. Due to the heterogeneous source material, the accuracy of the fit of the objects visible in the photos varies between 0.1 m (city centre) and 1.2 m (periphery). The raw mosaic file was subjected to masking up to 300 metres beyond the present-day administrative boundaries of the city. The final mosaic file is stored

[5] Unfortunately, in the free QGIS environment, each time changes are made during georeferencing, a new .tif file needs to be created (generated), which is a rather significant drawback of this package. The commercial software ArcMap (alternatively ArcGIS Pro) allows a live view of georeferencing changes without having to generate new result files, making it much more efficient to visually assess errors and make corrections.

Table 2. Selection criteria for objects to be calibrated – order of selection of Ground Control Points (GCPs)

No	Type of facility	Justification
1.	Elements of the geodetic and altimetric grid	Stabilised points in the field with a defined location and altitude. Protected by law, well documented and with the highest accuracy of the location. Unfortunately, they are difficult to identify in aerial photographs.
2.	UNESCO historic buildings; historic buildings in the "A" register of the voivodship	UNESCO is the highest level of protection. It covers unique sites of special value and strict protection status. Voivodship monument registers cover the basic level of protection at the national level. Important historic buildings are listed in the BDOT10k. It is important to note the date of construction of the object, most monuments date from before the Second World War, but sometimes there are particularly important later objects. Lists of objects with addresses are available on the websites of the Voivodship Offices for Historic Preservation and the National Heritage Institute (in Polish: Narodowy Instytut Dziedzictwa, NID) geoportal (www.mapy.zabytek.pl). Buildings on the "A" register cannot be rebuilt from the moment they are listed, unfortunately, it is not always possible to find out when they were listed.
3.	Buildings listed in the Municipal Registers of Historic Monuments (GEZ)	A lower level of protection, it has a complementary role to the Provincial Register of Monuments. Lists are maintained by individual municipalities. It is often possible to find designations of sites in Local Development Plans (LDPs) available in the SIPs of municipalities and counties. Objects may undergo minor redevelopment.
4.	Preserved buildings not covered by forms of protection	Many common objects. Pay attention to the shape of the object, we use the visible points of contact between the building walls and the ground for calibration. Tall buildings will be inclined, so the position of the roof in the photo may differ from the position of the foundations by up to several metres. The roof outline is often wider than the wall outline (eaves).
5.	Bridges and viaducts	Very durable structures with distinct structural elements. Railway bridges are better, being less frequently rebuilt. Caution, often new bridges are erected next to old bridges, the displacement may not be clear at first sight, but spoils the calibration result. The most important old bridges are marked in the NID geoportal.
6.	Railway tracks	Elements of great durability in the field, unfortunately identifying locations along the track can sometimes be difficult. It is useful to look for locations where the railway line intersects with roads or other elements of railway infrastructure.
7.	High voltage line poles, radio masts, observation towers	High durability and robust construction. Once built they are rarely rebuilt. Possible to interpret from the shadow. Note, we locate the base of the column and not the top.
8.	Roadside shrines and crosses	They are long-lasting objects, usually preserved in the same place and form for 50-, 100- or more years. Please note – during major roadworks it sometimes happens that chapels and crosses are moved entirely outside the road lane. It is difficult to recognise such objects on photographs at scales smaller than 1:10,000. At larger scales, they are visible due to their shadow.
9.	Intersections of paved roads	Moderately high field durability, good for calibrating materials at scales smaller than 1:10,000, where slight offsets in the field (1–2 m) will not affect calibration quality.
10.	Intersections of rural and dirt roads	Moderate or low sustainability. Many roads and footpaths in towns relate to earlier rural road layouts. In rural areas, there is often a lack of alternatives.
11.	Spits and field layouts with uniform ploughing direction	Plot boundaries, the course of baulks and field systems with uniform ploughing direction are very much linked to the lay of the land. These divisions very often go back a long way into the past and make it possible to reconstruct property demarcations going back as far as the Middle Ages. Important moments in history related to land ownership divisions are 1944 (decree on agrarian reform of the Polish Communist Party (PKWN)) and 1869 (Tsarist decree on the enfranchisement of villages and private towns of the Kingdom of Poland). Land ownership in the countryside is sacred.
12.	Other topographical features	If nothing else it is possible to attach to other landmarks: lone trees, and distinctive rock formations, but with reason.

in TIF (GeoTIFF) format, in 32-bit colour depth (RGB+a, where the “a” channel is a transparency mask), has dimensions of 37,064 × 43,643 pixels and occupies approximately 3.2 GB. The mosaic file has been tiled dividing the raster matrix into multiple small cache files to streamline data sharing over the Internet. The cache tiles were generated in two formats dedicated for use in web browsers or GIS software:

1) mosaic in the form of a set of folders of uncompressed tile files in .PNG cache format, 256 × 256 pixels and 32-bit colour depth (RGB+a). The tiles were generated using the tools available in QGIS Desktop 3.16. The tiles cover 14 levels of detail (5–18). The total number of files at all levels of detail is 41,496 tiles, grouped hierarchically into 368 folders and subfolders. The total volume of data is approximately 1.4 GB. The tiles were generated according to the TMS/XYZ protocol standard, in the Web-Mercator coordinate system (EPSG:3857).

Fig. 8. Georeferencing of an aerial photograph from 1944 *Lublin – Stare Miasto, Bronowice, Tatary*.
A – first-degree polynomial transformation (without changing the geometry of the photo, the resulting image has the largest local mismatch of control points); B – perspective transformation (trapezoidal distortion, preserving the internal proportions of the photo and the pixel sequence, moderate local mismatch of control points); C – folding transformation (TPS/adjust – segmentation of the raster matrix and linear interpolation of pixels in a variable-density triangular network, absolute matching of control points).
Own elaboration based on the NARA collection

2) Standardised mosaic files in ArcGIS Map Tile Package (.tpk) cache database format, were generated using the tools available in Esri ArcMap 10.8.1 software. The .tpk file contains 14 levels of .png tiles, compressed using the JPEG/LZ77 method. The matrix size at the highest level of detail (18) is 91,438 x 51,316 pixels. The weight of the file after compression is just under 0.4 GB. The tile database was generated in the Web-Mercator coordinate system (EPSG:3857).

3.4. Development of metadata

A detailed set of image metadata was developed based on the acquired image scans, the indexes available in the NARA catalogue and the descriptions available on the Fotopolska.eu website. The image metadata was linked to a spatial index developed in vector form (Zawadzki, 2021). The polygons covering the photo coverage are defined in the WGS84 (EPSG:4326) global coordinate system. Metadata files were developed and made available in standard spatial data exchange formats, i.e. ESRI Shapefile, GEOJSON, and GML/XML files. The metadata set includes:

1) inventory numbers in the NARA archive catalogue,
2) reference oleat numbers of the photo in the NARA archive,
3) inventory numbers in Fotopolska [if published],
4) the date the image was taken [daily if known],
5) photographed place [list of towns and districts of Lublin visible on the photograph],
6) the area covered by the photograph [in square metres],
7) flight altitude [in metres and feet],
8) the focal length of the camera [in millimetres and decimals],
9) the approximate scale of the photograph [from approx. 1:8,000 to approx. 1:41,000],
10) size of the raster matrix [from approx. 7,000 pixels per edge to approx. 12,000 pixels per edge],
11) the weight of the download [from approx. 8 MB to approx. 20 MB].

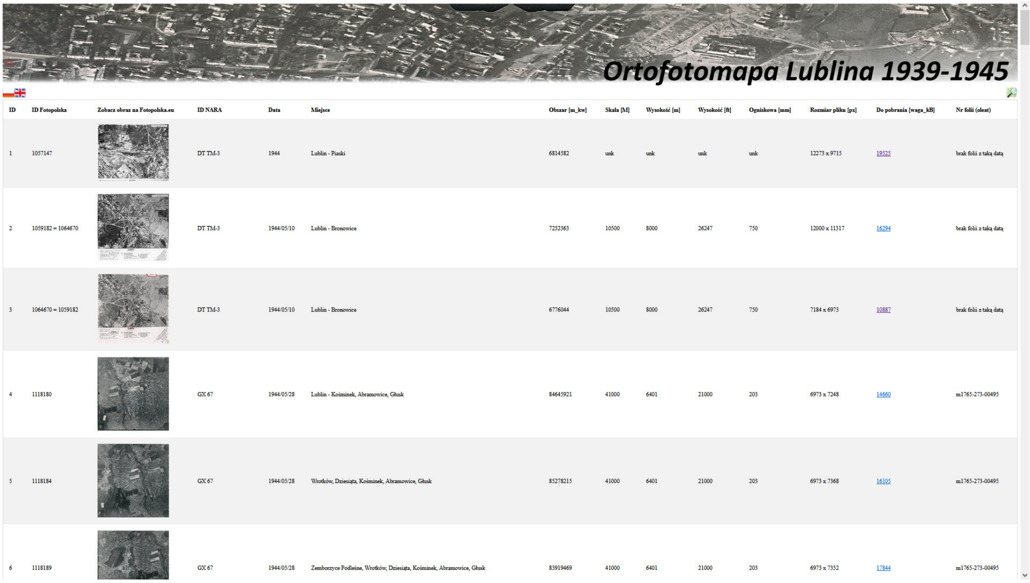

Fig. 9. *ortolub.umcs.pl* portal – the repository of downloadable images. Own elaboration

3.5. Publication of the collection

The implementation of the scientific activity resulted in high-quality historical spatial data. The excellent source material made it possible to develop a historical orthophotomap at a level similar to geodetic and photogrammetric elaborations at a similar scale (Ministerstwo Rozwoju, 2020). As a result, the historical orthophotomap of Lublin provides a reliable and credible source basis for the development of a database of the space of Lublin during the Second World War and further research work. The data acquired and produced as part of the project are made available without restriction, under the Creative Commons CC-BY-SA 4.0 licence (Creative Commons, 2022). The data are published and made available online, in Polish and English, through:

1) A web platform https://ortolub.umcs.pl/ based on non-commercial server solutions was created for this purpose (Kuna, 2021e). The platform is made up of three modules:

a. a digital repository (fig. 9) of archival aerial photographs that allows users to search images by metadata, download source files and view images using a web browser https://ortolub.umcs.pl/tab_pl.html;

b. a mapping application (fig. 10) based on the *Leaflet* open JavaScript library that allows viewing of historical orthophotomaps against archival maps and contemporary reference data, image search based on an interactive index, locality search, and filtering of images based on raid date https://ortolub.umcs.pl/map_pl.html;

c. spatial data services provided in the standard OGC XYZ/TMS protocol, enabling the implementation of the historical orthophotomap into standard Desktop GIS programs or standard WEB-GIS applications, *https://ortolub.umcs.pl/data/tiles_3857/{z}/{x}/{y}.png*. The project website provides accessible instructions for adding orthophotomaps to the most popular programs https://www.umcs.pl/pl/ortofotomapa-lublina-1939-1945-uslugi-gis,21828.htm.

2) ArcGIS Online platform with functionality similar to the map application (Kuna, 2021d), but providing alternative data hosting, collection retrieval and implementation into GIS programs via Esri Geospatial Cloud https://www.arcgis.com/home/item.html?id=d5dd97b49b014d6ea0e6bc221fc37668.

3) Zenodo platform, i.e. a CERN-run international research data repository providing a persistent DOI identifier. For aerial photographs of

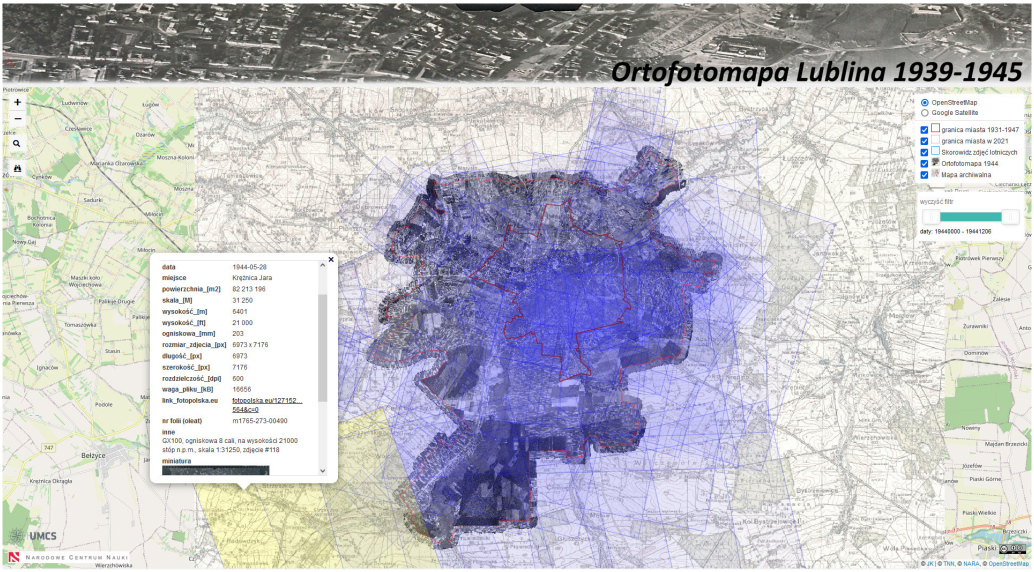

Fig. 10. *ortolub.umcs.pl* portal – the map application with historical orthophotomap layer and vector index. Own elaboration

Lublin (Kuna, 2021b), this is *https://doi.org/10.5281/zenodo.5638600*.

4) Wikimedia Commons (2022) platform, which is an open worldwide multimedia repository. A file of the historic orthophotomap of Lublin, 1 × 1 m, scale 1:10,000 and resolution 500 dpi *(https://commons.wikimedia.org/wiki/File: Lublin_1944_aerial_image)*, prepared for large-format printing, has been made available on Wikimedia Commons (Kuna, 2021a). Wikimedia Commons permits the copying, use and modification of any files uploaded to the repository, provided the source and author are acknowledged and the same free license is maintained for derivative works.

4. Use of *Luftwaffe* images in research in Poland

There is a widespread belief that information about the existence of a rich collection of the Second World War aerial photographs in the West only reached the country after the fall of the Iron Curtain. Some publications mention that the first Polish researcher to reach the collection of *Luftwaffe aerial photographs* in the American archive was the Varsavianist Z. Walkowski (Majewski & Urzykowski, 2004). On the other hand, in the publication by Mycke-Dominko (1992) we find information that the "discoverer" of the National Archives collection was Z. Rurarz in 1988. In the same study, Mycke-Dominko (pp. 111–112) states that photographs from these sources had already been at the disposal of the Photointerpretation Laboratory of the UW a decade earlier.

A turning point in the collective consciousness came in 2003 with the publication of the first German aerial photographs of Wrocław on the Fotopolska portal. Over the 20 years of operation (mostly thanks to user *Esski*), the portal has collected several thousand images – calling up the *National Archives and Records Administration* tag returns more than 7,000 objects, although not all objects are aerial photographs (Esski, 2022).

A huge contribution to the knowledge and systematisation of aerial photo collections was made by the staff of the Department of Photogrammetry, Remote Sensing and Spatial Information Systems of the Warsaw University of Technology (Różycki, 2010; Różycki et al., 2020a). Other publications on image processing methodology are also worth noting (Jucha, 2015). The photographs themselves have received numerous derivative studies, especially concerning the *Holocaust* (Hebrew: *Shoah*) and Polish sites of martyrdom (Mirończuk & Poławski, 2015; Ossowski et al., 2018; Różycki et al., 2020b). Similar research is also conducted using post-war and later photographs, which demonstrates the universal nature of the methods used (Dukaczewski et al., 2017).

Archival aerial photographs as cartographic/illustrative sources can be found in numerous local and regional studies on urban space (e.g. the Polish Historic Towns Atlas series). In digital form, photographs from the period of the Second World War are available, among others, on the Warsaw City geoportal (Mapa.um.warszawa.pl, 2022), and the same on the geoportal of the Fundacja Warszawa1939.pl (2022). Individual images are also available for other cities (e.g. Forum.Odkrywca, 2010). An interesting proposal, although based on later photographs, is the Retromapy application of MGGP Aero (2022). However, it is difficult to find studies describing the methodology of developing these. The possibility to browse thumbnails of post-war aerial scans has also been enabled by the National Geoportal (fig. 11, Geoportal.gov.pl, 2021). The high-resolution scans can then be ordered through the PZGiK portal at a cost in the order of 25–30 zł per unit. This is not an optimal solution, but it raises hopes for systematic development and provision of mosaics of archival aerial photographs in the future, e.g. in a similar way to the views provided by the Hungarian Arcanum Maps (2022).

5. Historical recognition of the transformation of Lublin during the war period

Lublin has a considerable number of scholarly studies on the history of the city, including many detailed studies devoted to particular periods, people, places and events. The historical studies of Lublin to date use mainly ground photographs and descriptive documentation. There are relatively few synthetic studies considering the transformation of the city's space based on cartographic materials (Chachaj et al., 2017; Harasimiuk et al., 2007; Kociuba, 2016; Przesmycka, 2012). Works of this kind, although very valuable, due to the size of the city and the richness of the topics covered, have limited detail. Tracing the changes in the development of Lublin during the Second World War is made difficult by the scarcity of cartographic documentation. The most important pre-war cartographic source is the *Plan Wielkiego Miasta Lublina on a* scale of 1:1,000, in the form of 101 sections measuring 80 × 50 cm – this ma-

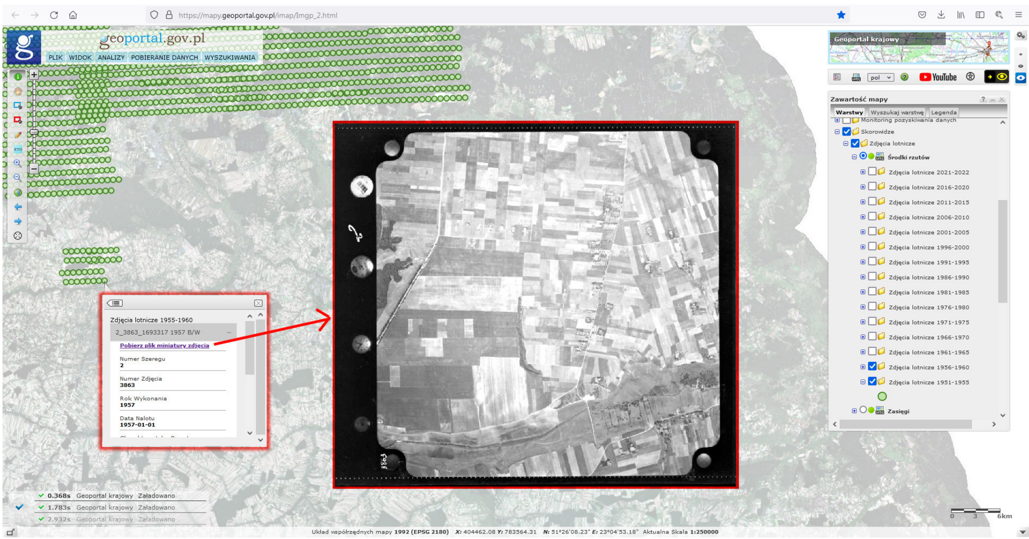

Fig. 11. Geoportal.gov.pl – index of archival aerial photographs from the 1950s with point distribution of projection centres, description of image metadata and downloadable thumbnail view. Own compilation based on geoportal.gov.pl

terial is little known and its research use to date is negligible.[6] Only 3 maps of the whole city at a scale of 1:10,000 have survived from the decade 1930–1940, which allows the particular identification of all buildings. The earliest map published after the war is a 1:10,000 map from 1947. Unfortunately, confrontation of the post-war map with other historical materials has shown that only selected parts of the space have been updated (Kuna, 2021c).[7] In many places, the content of older maps was redrawn without introducing changes, which, given the two waves of bombing, the construction of the *KL Lublin* concentration camp and the extermination of the Jews, were significant (Dymmel & Rodziewicz 2012; Kłapeć, 2017; Kuna & Kowalski, 2020; Kuna, 2021c; Przesmycki, 2008; Szewczyk, 2019). It is also important to note that the content of the described maps is limited to the administrative boundaries of the time and covers less than 20% of the current area of the city. For this reason, knowledge of areas outside the city limits from 1931–1947 is perfunctory (Kuna, 2021c). The only real chance to fill such serious gaps in the history of changes to the city's space is the study of archival aerial photographs. The project *Orthophotomap of Lublin 1939–1945* provides a detailed, reliable and objective source basis for such research. The preserved aerial photographs make it possible not only to identify individual buildings but also to locate places where bombs fell or to locate anti-aircraft artillery positions (Dymmel & Rodziewicz, 2012; Przesmycki, 2008; Szewczyk, 2019).

6. Summary

From a local perspective, the project was a success. The publication of the historical orthophotomap of Lublin aroused the interest of the scientific community and the media. Broadcasts concerning the project were aired, among others, by TVP3 Lublin (twice), Lublin radio stations and several popular Internet websites. A report on the project was published in the national magazine Geodeta (Kuna, 2021c). In the sphere of social impact, agreements were signed for the inclusion of the historical orthophotomap in the Spatial Information System of Lublin (Geoportal Lublin, 2021) and the Historical Geoportal of Lublin ("Grodzka Gate – NN Theatre" Centre, 2021). The project was presented at the *XLIII Polish National Cartographic Conference* (2021, October 27) and as part of the lectures of the Lublin Branch of the Polish Geographic Society (2021, December 2). The use of aerial photographs of Lublin from the Second World War is of interest to representatives of various scientific disciplines: archaeologists, historians, and physical and social geographers. More publications based on this unique dataset are expected soon.

The completion of the project in the local sphere also prompts reflections of a supra-regional nature. Firstly, the technical procedures described in this article are universal, largely (although not 100%) based on OpenSource software and allow the production of a historical orthophotomap for any area. Unfortunately, the significant labour intensity of the digital processing of the images requires the search for optimisation solutions – especially in the area of automation of georeferencing, the results of which will have an accuracy comparable to contemporary orthophotomaps at a similar scale.[8] The development of new procedures is necessary to move from individual craftsmanship to mass production of historical orthophotomaps.

Secondly, the vast collection of the Second World War aerial photographs held in the NARA archive has enormous research potential. Acquiring the images, inventorying them, describing them with metadata, processing them into spatial data services and publishing them in publicly accessible digital repositories is a major challenge for the Polish scientific community. The example of the orthophotomap of Lublin for the year 1944 shows that it is necessary to undertake this effort – the aerial photographs of the

[6] An exception is a publication edited by Chachaj et al. (2017). Thanks to the author of the present text, the combined Plan of the Great City of Lublin on a scale of 1:1,000 in a black and white copy can be viewed in interactive form in the Spatial Information System of Lublin (Geoportal Lublin, 2021) and the Historical Geoportal of Lublin ("Grodzka Gate – NN Theatre" Centre, 2021). More about the methodology of developing the Historical Geoportal of Lublin in Kuna and Kowalski (2020).

[7] Scans of 1934, 1938 and 1947 plans are available from the Lublin Digital Archive (Lubelskie Archiwum Cyfrowe, 2022).

[8] Example procedures for automating georeferencing using ArcGIS PRO have been published by Andrew (2017). The author's experiments have shown that processing monochrome archival images using this method is still unreliable.

Luftwaffe collected at NARA are the oldest consistent, relatively complete and relatively accessible documentary material for the area of Poland on such a large scale. Its acquisition will open a new era in terms of the quality and detail of geographical and historical research. This applies not only to the Second World War period but also to prospectives up to the 1950s and retrospectives for earlier decades.

Thirdly, on the one hand, the involvement of the central bodies of the Geodetic and Cartographic Survey in the digital inventory of archival aerial photographs from the PZGiK collections (Geoportal.gov.pl, 2021), and on the other hand, existing examples from other countries (Arcanum Maps, 2022) show that the production of – correctly located and of good quality – historical orthophotomaps of national coverage is possible. With the appropriate development of georeferencing automation procedures, within the next few years, the GUGiK will be able to produce coverage of the country with mosaics of images from the communist period. The inclusion of the Second World War images seems a natural next step. This is an undertaking of sufficient size and complexity to be done within the framework of research cooperation between GUGiK and the CENAGIS scientific network.

Acknowledgements. The author would like to express his sincere thanks to the following people who provided help, advice and technical support during the project: Patryk Bilski, Bogdan Błoński, Dr Beata Konopska, Prof. UMCS, Adam Kieliszek, Anna Kuna, Mariusz Siudem, Dr Mateusz Zawadzki.

The author would like to thank two anonymous reviewers and editorial staff for their valuable guidance and supplementary material to the text.

The project *Development of the Ortophotomap of Lublin 1939–1945* was carried out in the Department of Geomatics and Cartography of the Maria Curie-Skłodowska University in Lublin, under the grant of the National Science Centre – Miniatura 4.0. no. 2020/04/X/HS4/00382.

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