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METHODS OF GATHERING SPATIAL DATA FOR ARCHAEOLOGICAL RESEARCH UPON THE ROMAN FORT IN BOLOGA (ROMANIA)¹

ABSTRACT The North-western border of the province Dacia is one of the least-known parts of the Roman *limes*. In the years 2016-2017 spatial data was acquired in the environs of the Roman fort Resculum/Ruconium in Bologna which permitted the documentation of the remains of the Roman constructions. The methods and analyses utilized are a valuable contribution in the development of the methodology of archaeology. Extensive archaeological research and surface survey in the environs of the Bologna were conducted by the Institute of Archaeology in Toruń and the National Museum of Transylvanian History in Cluj-Napoca.

Keywords: Dacia, Resculum, LIDAR, geophysics, archaeology

ABSTRAKT Północno-zachodnia granica rzymskiej prowincji Dacji, to jeden z najmniej znanych odcinków rzymskiego limesu. W latach 2016-2017 r. dla okolic rzymskiego fortu Resculum/Ruconium w miejscowości Bologna zostały pozyskane dane przestrzenne, które pozwoliły zadokumentować pozostałości rzymskich konstrukcji. Metody ich pozyskania i analizy stanowią cenny wkład w rozwój metodologii archeologicznej. Archeologiczne badania szerokopłaszczyznowe oraz prospekcja terenowa są prowadzone okolicach Bologna przez Instytut Archeologii UMK w Toruniu we współpracy z Narodowym Muzeum Historii Transylwanii w Kluż-Napocze.

Słowa kluczowe: Dacja, Resculum, LIDAR, geofizyka, archeologia

The Roman auxiliary fort in the town of Bologna was constructed on a high terrace, near the Săcuieu stream that flows into the river Criş. The river valley connects the Transylvanian Plateau and the western flatlands of the Cisa river. One can suggest that the strategic role of this fort was the protection of the western boarder of the province or, and more probably, it had been located there as a means of controlling trade and the flow of people. In the light of an inscription (CIL III 8060) discovered at Almaşu Mare near Bologna (on the road from Sutoru to Optatiana) the name previously assigned to the fort, Resculum (TIR L 34, 196)² has to be questioned. Currently the name Ruconium is considered to be more probable³.

In its first phase the fort was a small establishment: a 160x125 metre rectangle⁴. It had been constructed before the year 123⁵ as in this year we first have information about the presence of *coh. I Aelia Gaesatorum* in Dacia Porolissensis, or before 154, as in this year the *coh. II Hispanorum* was relocated to Bologna⁶. The rectangle based fort had its *porta pretoria* facing North⁷. All of its stone gates had been given semi-circular towers, which can be dated to the Early Severan Period. Only the *portae principales* are double-gated, although the *praetoria* and *decumana* are sufficiently wide

⁴ Gudea 1997c: 17.

⁵ Compare the military diploma in: Eck, Pangerl 2011.

⁶ N. Gudea saw the increase in the size of the fort to 125 x 235 m in the years 125-126 and connected it to the arrival of the Gaesati (Gudea 1997c: 26). *Coh. II Hispanorum* may have been mentioned in the military diploma from the year 128 but only one digit prevailed. (Ciongradi, Bota, Voişian 2009).

⁷ The layout of the fort in Marcu 2009: 26-28, the newest information in Marcu, Cupcea 2015: 75 passim.

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² Discussion of the name can be found in: Torma 1880: 11-59; Macrea 1969: 154-155; Gostar 1969: 175-176; Bogdan-Cătănicu 1981: 51; Bogdan-Cătănicu 1991: 63-64; Wollmann 1996: 67; Gudea 1997c: 8-9, 48.

³ Bogdan-Cătănicu 1991:63-64; Nemeti 2006: 281; Ardevan, Zăgreanu 2012: 78-79.

in relation to the gates⁸. What is interesting is that they are not located on the exact axes of the fort, but 10 metres towards the west. This is why the structures in the *praetentura dextra* and the *retentura dextra* are longer than the ones located in the *sinistra* section⁹. This might indicate that the interior was divided into one part (*sinistra*) dedicated to a single unit and the other (*dextra*) for a second unit belonging to the same garrison¹⁰. The site in Bologna proved to be a good training ground for the application of new methods, which could be helpful both in the documentation of particular constructions, as well as in the spatial analysis of the settlement micro regions.

On the site in Bologna a state of the art method of obtaining spatial data, based on the technology of laser scanning – LIDAR was used. In early literature the acronym stood for Light Detection and Ranging, however currently it is most often understood as Laser Imaging, Detection and Ranging¹¹. The latter name seems to be the more accurate one as today's methods of remote sensing are laser-based¹². The basics of the measuring are simple: the device emits a beam that returns to its source after reflecting off an object. The measuring instrument is therefore both the emitter/source and the receiver of the laser impulse, and the data gathered is based on the time it takes the beam to reach the object, reflect back and return to the instrument, as well as on the information concerning the available angles of reflection. This allows for the establishing of the angular position and the distance between the object and the instrument. During the process, not only the coordinates of particular points are acquired, but also other data such as the intensity, the time it takes the beam to return, or, with the help of other tools and algorithms, the RGB colour value. LIDAR is a method of collecting spatial data characterized by a high level of precision and speed. It allows for the registering of up to a million points in just a single second.

During the excavations in the fort of Resculum two methods of LIDAR were utilized. The first was ground-based, the second was aerial. These differ in their purpose, the level of complexity of the tools used, and the technology of remote sensing. In both of the cases the registration of data was based on a reference frame and a coordinate system, necessary

to establish the precise position of a point, and to retain an identical physical determination of a singular point¹³. Each coordinate system is understood as the position of a point within a space, be it two-, three-, or four-dimensional, and is entered into a reference frame – a set of observed parameters describing the frame, scale, the axis and their changes in time. This frame is defined by the reference system – recommendations and arrangements together with the description of the model necessary to define the beginning, scale, axis and their changes in time¹⁴.

The method of ground-based scanning is dependent on defining a coordinate system within the device and providing it georeference through imputing points of known three-dimensional coordinates. Only after that the instrument is ready to begin measuring within the existing reference system. The method of Airborne Laser Scanning (ALS) is a more complicated process. The basic principle of a laser rangefinder remains the same and is based on the LIDAR technology, with high frequency laser pulses that sample an area, perpendicular to the direction of the flight¹⁵. LIDAR uses the Global Navigation Satellite Systems (GNSS) and the Inertial Navigation system (INS)¹⁶. GNSS is responsible for the location of the plane, while the INS measures the angular inclination and the acceleration vectors of the platform housing the scanning head. Only after combining the data from the three systems is the designation of a terrain point possible. Both methods retain the basics of an electronic tachometer, where in the ground-based method hinges on the georeference data being inputted into the device before or after the measurements, while in the ALS system the position of each point is defined 'on the fly' through the integration of data from other systems.

For the acquiring of spatial data on the ground, instruments of Leica Geosystems¹⁷ were used – the Leica Nova MS60 station (Pic.1A) in 2016 (leica-geosystems.com/pl-PL/products/total-stations/multistation/leica-nova-ms60, accessed on 02.11.2018) and a ScanStation P50 HDR scanner

⁸ Gudea 1997c: 33-34.

⁹ Additional details in Marcu 2009: 27-28.

¹⁰ Marcu 2009: 28.

¹¹ Banaszek 2015: 39.

¹² Pilecki 2012

¹³ Kryński, Rogowski 2004: 14.

¹⁴ Ibidem.

¹⁵ Kuczyński 2015: 59.

¹⁶ Ibidem.

¹⁷ The authors would like to thank Leica Geosystems Polska for providing the instruments. Additional acknowledgements to Michał Mikołajczyk and Robert Szyszko for their help in preparing and conducting the field measurements as well as the primary processing of the data gathered.

(Pic. 1.B.) in 2017 (leica-geosystems.com/pl-PL/products/laser-scanners/scanners/leica-scanstation-p50, accessed on 02.11.2018).

Leica Nova MS60 allows for scanning using a precise long-range laser (from 1,5 up to 1000 metres). The device is capable of scanning up to 1000 points per second from an object located 300 metres away. Increasing that distance only slightly reduces the speed of the scanning. The precision of the device is 1 arc second, and the range of density of scanning starts from 0.5 centimetres. The instrument collects data on the location of points, the intensity of the reflection and the RGB colours which is possible thanks to the 5 megapixel CMOS sensor capable of achieving a frame rate of up to 20 fps.

Leica ScanStation is an advanced, ground-based, long-range laser scanner. This instrument can scan up to 1 million points per second. Its range varies from 40 centimetres to 1000 metres. The accuracy of the station is 8 arc seconds which allows for the scanning with a 3 millimetre precision for distances over 570 metres from the target. The possible density of scanning from 50 metres is 2 millimetres. It can be operated 360 degrees horizontally and 290 degrees vertically. It is equipped with a 4 megapixel camera. As with the previously mentioned Leica Nova MS60 the ScanStation collects data on the location of points, the intensity of the reflection and the RGB colours. The scanning using the ALS method was conducted for the University by the MGGP Aero¹⁸ partnership. For the surface of approximately 50 square metres a full-waveform scanner was used to obtain a 4 pts/m² cloud, with a high accuracy of 0.15 metres and a 30% lateral cover.

The methodology used for obtaining spatial data in the 2016 and 2017 seasons was dictated by the goals that had been set by the researchers. In the 2016 season the main focus was the documentation of the architectural remains unearthed during excavations. The first of these were the stone constructions located in the central part of the site. Next the exposed walls of the northern tower of the fort were recorded. In 2017 a broader-range, ground-based measuring was carried out along with the ALS scanning. The main goal of the ground-based research was the recording of the largest possible area of the fort. The interior of the fort was scanned, including the archaeological trenches. Additional measurements were made in the adjacent areas to

the north, east and south of the fort. The high density of foliage growing west of the fort, made scanning difficult which resulted in the decision not to gather data from that area. The culmination of the measuring was ALS scanning conducted on an area of 50 m² lying adjacent to the fort of Resculum.

In the 2016 season Leica Nova MS60 and the GPS/GNNS receiver Leica Viva GS14 were used. Before the scanning a geodetic network was established using the Leica Viva GS14 which allowed for the orientation of the device – to georeference it – by using a method of resection to at least three points, which have known coordinates. After the establishing of subsequent sites for the scanning the measuring began. The Leica Nova MS60 allows for the adjustment of the density of the surface being scanned. For the architectural remains a scan with a density of 1 centimetre was used, while for the remaining terrain the density was set to 10 centimetres. This optimized the time taken for scanning, whilst maintaining good parameters of density in the points being measured.

In the next season the scanning was conducted using the Leica ScanStation P50 HDR scanner using the Leica Viva GS16 GPS/GNNS RTK receiver. As in the process in which the Leica Nova MS60 was used, the method of orientation using resection to at least three points with known coordinates was chosen. Due to the extent of the area being scanned, the points of the geodetic network were established using the Leica Viva GS16 (Pic. 2.A. and 2.B.), and were marked with special plates (Pic. 2.C). In the interior of the fort a number of points in that network was set and marked so that they could be seen from various locations by the scanner. In the case of the environs of the fort these points were established ‘on the fly’, depending on the physiographic features and the progress already made. Each of the plates was given a number which enabled the connecting together of the separate scanned images into a single one in the post-processing. During the scanning of the fort’s interior, special attention was paid to the archaeological trenches for which the maximum density of scanning was used. For the areas lying outside the fort, the density of scanning was set at less than a decimetre. The ground based scanning was based on the local geodetic network. The datum used was the national, Romanian network. The Leica Viva GS16 was connected with the state’s network of reference stations allowing the RTK measurement to be gathered with a margin of error in three dimensions not greater than 1.5 centimetres. The ALS scanning was made with a full-waveform scanner on an area of 50 m². During the passes over the area a cloud of points

¹⁸ MGGP Aero Sp. z o.o., ul. Kaczkowskiego 6, 33-100 Tarnów.

(4 pts/m²), with a high accuracy of 0.15 metres and a 30% lateral cover was created.

The result of the LIDAR scanning is a three-dimensional point cloud (Banaszek 2015, 55). Depending on the instrument used the cloud is able to contain metadata of various types. The most important are the three-dimensional coordinates, so the points location and its altitude (Pic.3.A). But these can contain the angle and metric data, should a specific systems and reference system be in use. Additional information that can be gathered when using the LIDAR scanning is the intensity of the reflection of the beam (Pic.4.A) and the RGB colour in the point (Pic. 3.B) which give the possibility to visualize the cloud in three dimensions. Important in the post-processing, and this pertains especially to the ALS method, is the information on the type of echo, pointing to the phases of the beams reflection (first echo – intermediate echo – last echo) which has an impact on the later classification of that point in the phase of data processing. Among the registered metadata there is also information on the order of scans/passes made over the area and the GPS time: the sequence of registering of the individual points. The base result of the LIDAR scanning, especially when using the ALS method, is a Digital Surface Model (DSM). This is an image of the Surface which includes foliage and infrastructure objects¹⁹. In archaeological research the most popular result of the LIDAR scanning is the Digital Terrain Model (DTM) – a structured set of points representing the altitudes of the surface of an area with the interpolation algorithms²⁰. These algorithms allow the reconstruction (interpolation) of the surface within a random space, which means that one can determine the altitude of a point based on its plane coordinates. The most basic interpolation algorithm is the GRID model (Pic.5) formed on the grid of squares, with their nodes being given a specified altitude and the data are stored in a matrix. The limitation of this model is the omission of contour lines, whose visibility is enhanced when using the Triangular Irregular Network (TIN) interpolation model. This is based on a grid of triangles (Pic.4.B.) created from established mathematical criteria²¹. The combinations of these methods of interpolation are the hybrid models based on the GRID model with additional layers representing the contour lines or the TIN model²².

In 2016 during the scanning conducted with the Leica Nova MS60 a cloud of points was created (Pic.3 and 4), with additional data in the form of RGB values (Pic.3.B) and the intensity of the beam's reflection (Pic.4.A) This data enables a three-dimensional visualization of the scanned objects. Picture 3 shows a part of remains of the northern tower presented as a cloud of points and also as a cloud of point with added colour. For the purposes of recording the surface of the site and the remains within the fort which had been excavated in the central part, a Digital Terrain Model of the trench was made (Pic.4). From the point cloud obtained a TIN was interpolated which was subsequently symbolised with colour, highlighting the contour lines of individual objects.

The biggest amount of data was obtained from the ALS scanning conducted in 2017. In the post processing a XYZ point cloud was created representing the location of individual points. Furthermore the results of ALS scanning were transformed and saved in LAS format. To maintain accordance within format standards for all the points the following data was acquired and assigned to the coordinates: the intensity of the beam's reflection, the echo of each reflection, the overall number of echoes, the direction of scanning, the place of each point in a line, the belonging of individual points to classes, the angle from which the device emitted the beam, the time it took to scan a point, the RGB value²³. The methodology of processing the data from ALS scanning consisted mostly of extracting, calibrating and georeferencing the point cloud. The next step was the lowering of the altitude attribute of the point cloud into a geoid. Finally the point cloud was refined by filtering out the extreme values.

The contract with MGGP Aero included the processing of the point cloud. The most important feature was its coherence to the ASPRS (American Society for Photogrammetry and Remote Sensing) standards. This classification identifies the following classes of points²⁴: class 1 – Created, never classified (these consist of means of locomotion such as parked cars, overhead power lines, clusters of temporary objects); class 2 – Ground (points located on the surface level such as hills, slopes, dunes, and all of the objects constituting the integral parts of the environment); class 3 – Low Vegetation (points representing vegetation ranging from 0 to 0,40 metres); class 4 – Medium Vegetation (points representing vegetation ranging

¹⁹ Borkowski 2015: 124.

²⁰ Borkowski 2015: 110.

²¹ Borkowski 2015: 110-111.

²² Borkowski 2015: 111.

²³ Kuczyński, Stojek, Cisło-Lesicka 2015: 34-35.

²⁴ Kuczyński, Stojek, Cisło-Lesicka 2015: 35.

from 0,40 to 2 metres); class 5 – High Vegetation (points representing vegetation above 2 metres); class 6 – Buildings (points representing buildings, constructions, bridges, dams, weirs, and other structures); class 7 – Low Point (noise – this represents errors and altitudinal peaks)

Some of the operations have been carried out automatically, with the usage of algorithms based on ALS data classification. The automatic classification of the point cloud was made using the TerraScan program from the TerraSolid suite. The algorithms used allowed for the automatic classification of clouds into the following classes: Low points, Air points, Isolated points – points that are considered noise (class 7 mentioned above); Ground (class 2) – classified using an appropriate macro with the device parameters being tested earlier on the physical landscape and the nature of the coverage; Foliage (classes 3-5) – created by the filtering out of data from the above mentioned Ground class (the algorithm creates a triangle based model for the Ground class); Buildings (class 6) – structures, bodies of water, hydrotechnical buildings and others classified using the marked out polygonal outlines after manual corrections. The data above have been verified with the help of orthophotography. The errors that were apparent are then corrected, bearing in mind the information from the data in the point clouds. Each section is then verified in regard to the full coverage of the particular sections.

Based on the files generated in this way it was possible to interpolate a Digital Surface Model. This model was created by the TerraSolid software by using a GRID with a raster spacing of 0.5 metres established on a triangle-based model created by the points gathered by the first reflection of LIDAR. The Digital Surface Model was then verified with orthophotography and corrected, considering the information from the data in the point clouds.

In archaeological research, especially in the prospecting of anthropogenic features located in a limited access terrain, such as mountains, forests, the Digital Terrain Model is one of the most useful tools. Similarly to the above mentioned Digital Surface Model the points from class 2 – the Ground – were also interpolated to a Digital Terrain Model of the environs of Bologna (Pic.5 and 6.). Digital Terrain Model was also created on the TerraSolid software by using a GRID with the raster spacing of 0.5 metres established on a triangle-based model created by points gathered by LIDAR. Due to the triangle-based model, in the low-density areas of the cloud, it was possible to ascribe Z-values to individual points of the GRID which resulted in the completing of the model.

The image of the surface of the environs of the Resculum fort obtained can be the subject of further spatial analyses. The results may be a visualization of the material acquired during the LIDAR scanning²⁵. The instruments that form the basis of this process are the Geographic Information Systems which have in-built tools and algorithms for visualization. Among the most popular ones is the shadow analysis (or a similar 16 points of shading analysis), but also transformations generated by algorithms of Sky-view Factor, Local Relief Model, Openness, Principal Component Analysis (PCA)²⁶. One of the examples of products of ALS scanning is shown in picture 6. The issue of secondary processing, the obtaining of secondary results from LIDAR or ALS is a more complicated matter than the process of collecting the spatial data and will be the basis for further research of the environs of the Roman fort in Bologna.

The methods presented of collecting spatial data are a substantial tool of prospection and archaeological analysis. The use of these methods yields good results especially in archaeological research focused on the presence and extent of settlements located areas which are hard to access.

Abbreviations

CIL – Corpus Inscriptionum Latinarum, 1863- .
TIR – Tabula Imperii Romani, 1931- .

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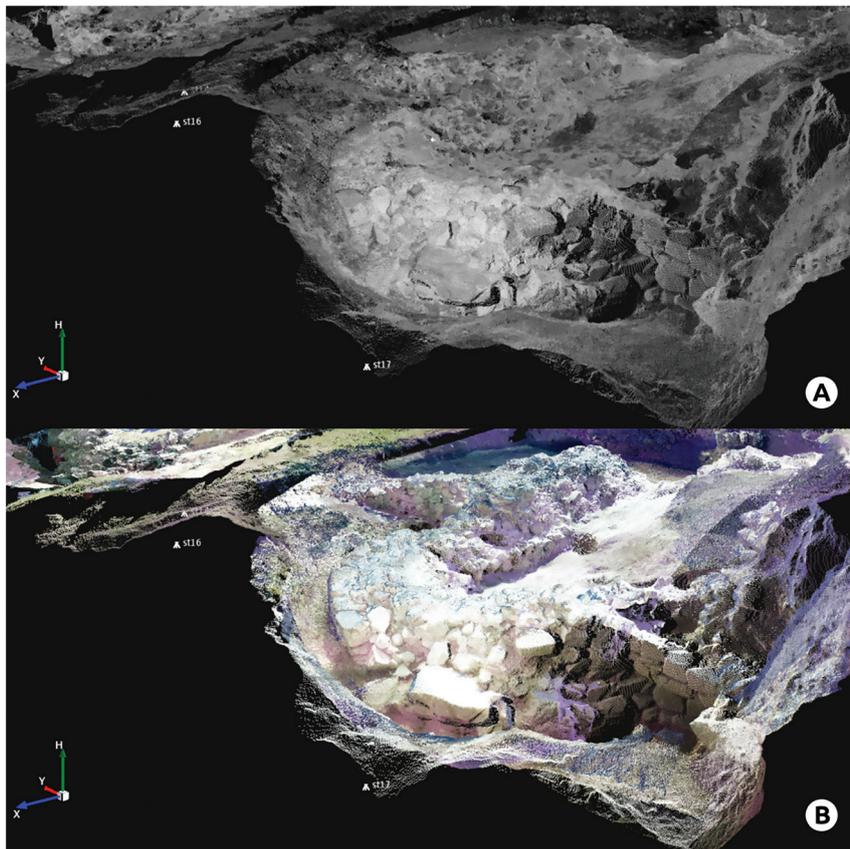
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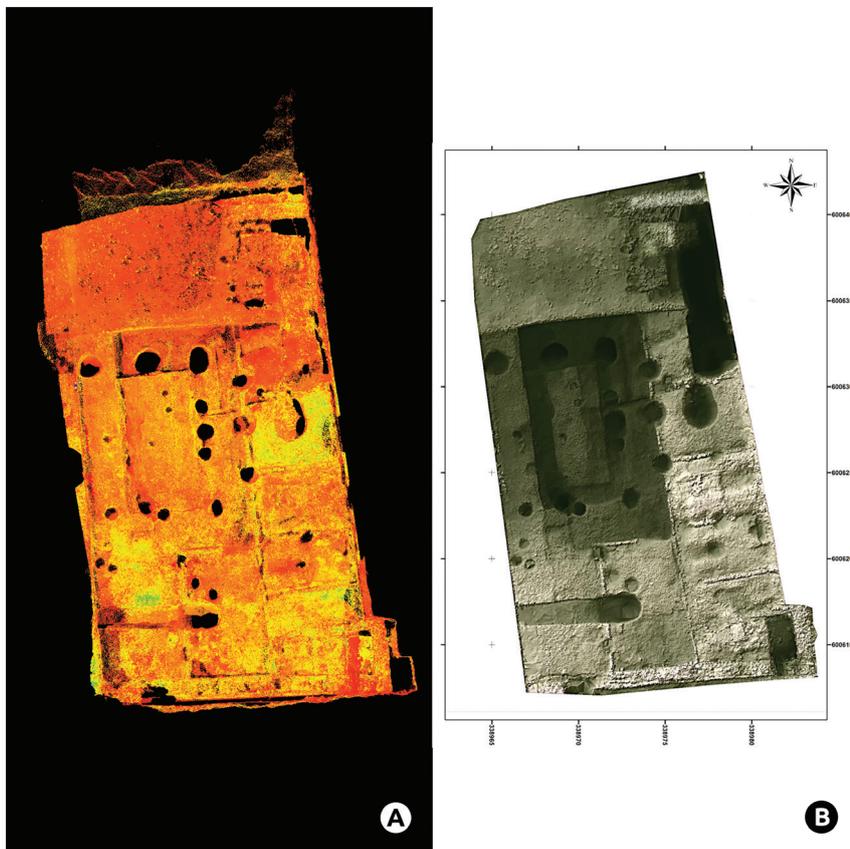
Pic. 1. Bologna, fort Resculum. Instruments used for scanning A – Leica Viva MS60 (year 2016), B – HDR Leica ScanStation P50 (year 2017) (Photo: T. Górzynski)



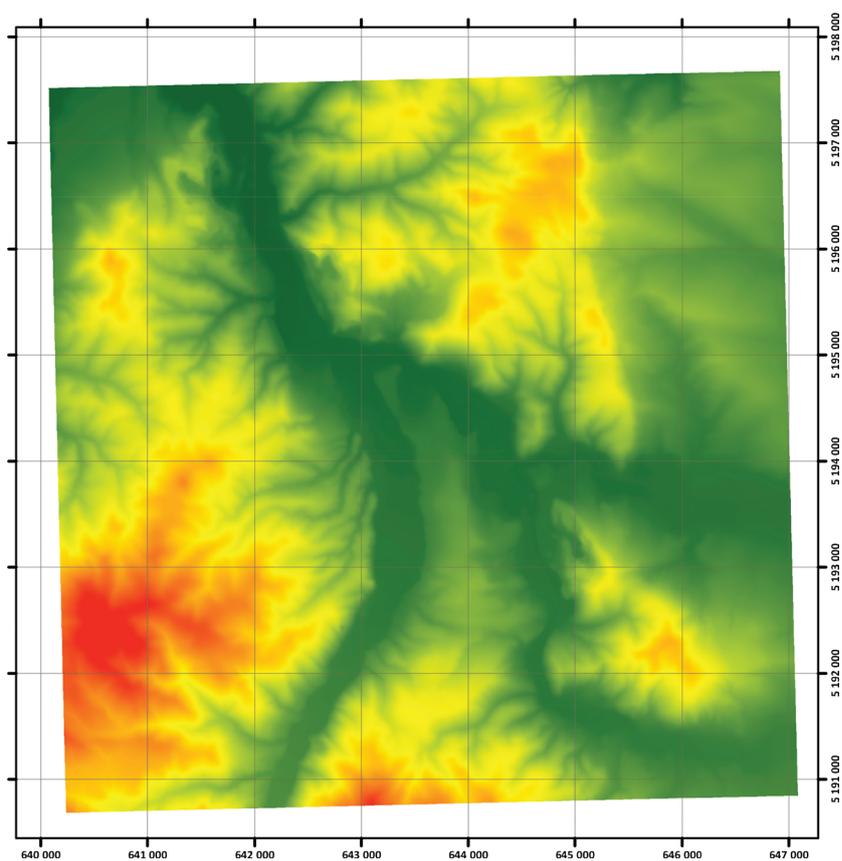
Pic. 2. Bologna, fort Resculum. HDR scanning with Leica ScanStation P50 (year 2017). A and B Establishing the geodetic network using GPS/GNNS RTK Leica Viva GS16, C – plate used as a part of the geodetic network (Photo: T. Górzynski)



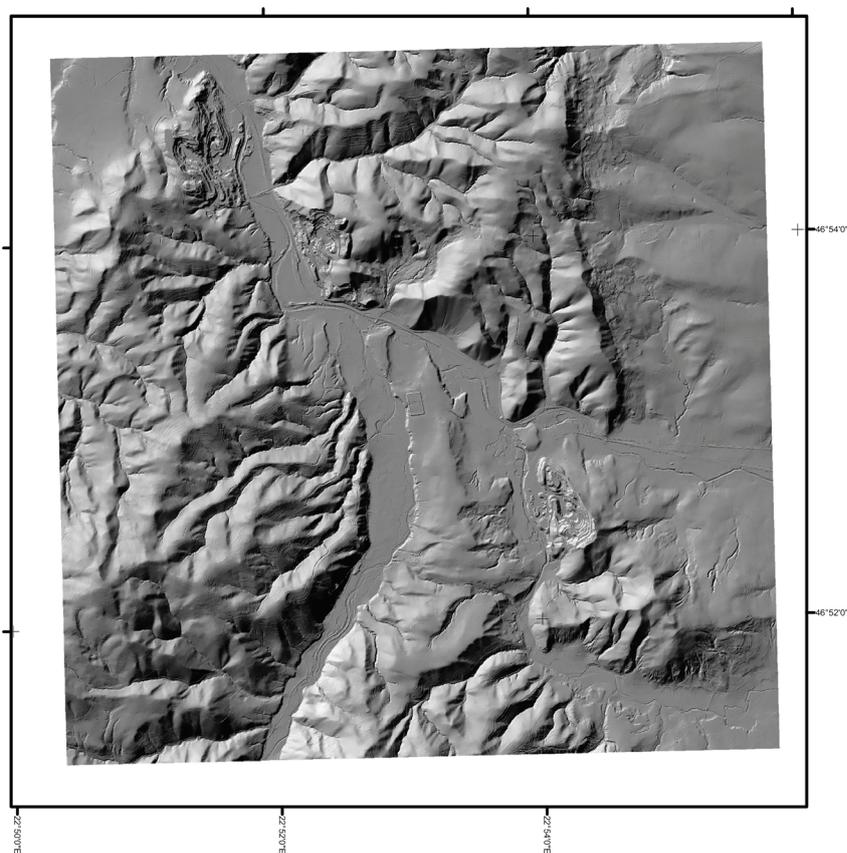
Pic. 3. Bologna, fort Resculum. Results of scanning using Leica Viva MS60 (year 2016).
 A – point cloud, B – point cloud with added RGB values (by T. Górzyński)



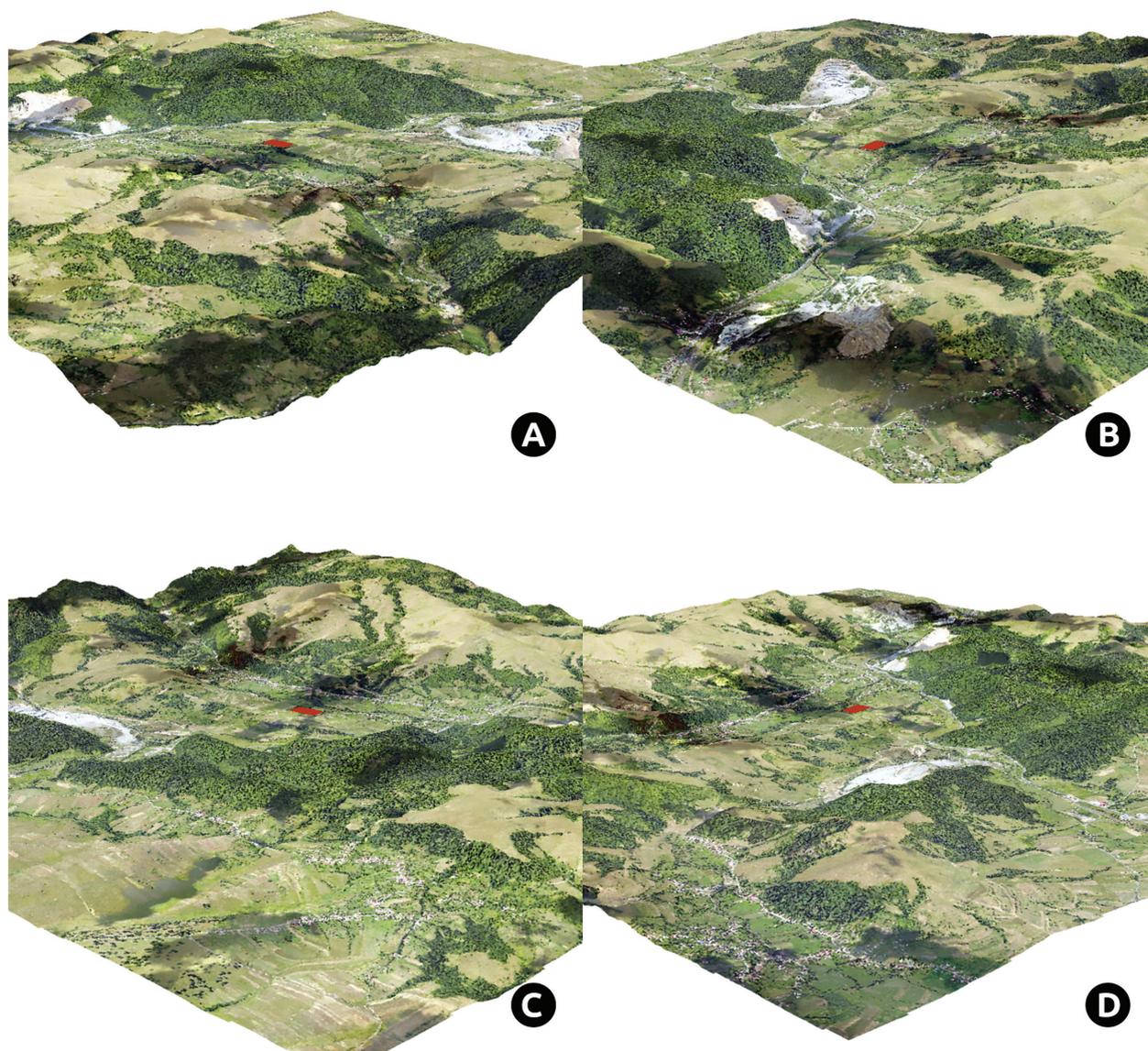
Pic. 4. Bologna, fort Resculum. Results of Scanning using Leica Viva MS60 (year 2016).
 A – point cloud, B – Digital Terrain Model, TIN interpolation with colors added as an example (by T. Górzyński)



Pic. 5. Bologa, fort Resculum. Results of ALS scanning (year 2017). Digital Terrain Model, an example of altitude marking (by T. Górzyński)



Pic. 6. Bologa, fort Resculum. Results of ALS scanning (year 2017). Digital Terrain Model, example of using shading of hills (by T. Górzyński)



Pic. 7. Bologa, fort Resculum. Results of ALS scanning (year 2017). Digital Terrain Model, a 3D ortophotography.
A – viewed from the south-west, B – viewed from the north-west,
C viewed from the north-east, D – viewed from the south-east, (by T. Górzyński)