# ANTÆUS

39

# ANTÆUS

*Communicationes ex Instituto Archaeologico*

39/2023

*Sigel: Antaeus*

# ANTÆUS 39

*Communicationes ex Instituto Archaeologico*

Communicationes ex Instituto Archaeologico

Distribution of exchange copies by
the Library of the Institute of Archaeology, HUN-REN Research Centre for the Humanities
H-1097 Budapest, Tóth Kálmán utca 4.



HU ISSN 0238-0218

Desktop editing and layout by Archaeolingua
Printed in Hungary by the Prime Rate Kft.
Cover by H&H Design

## INHALT – CONTENTS

## LIST OF AUTHORS


BELÉNYESY, KÁROLY
Mayor's Office of the City of Székesfehérvár
H–8000 Székesfehérvár, Városház tér 1.
belenyesy@gmail.com

BERTA, ADRIÁN
Institute of Archaeology,
Research Centre for the Humanities
H–1097 Budapest, Tóth Kálmán utca 4.
berta.adrian@abtk.hu

EKRIK, ÁKOS
Institute of Archaeology,
Research Centre for the Humanities
H–1097 Budapest, Tóth Kálmán utca 4.
ekrik.akos@abtk.hu

FERENCZI, LÁSZLÓ
Ústav pro archeologii
Univerzita Karlova, Filozofická fakulta
CZ-116 38 Praha 1 nám. Jana Palacha 1/2
Laszlo.Ferenczi@ff.cuni.cz

GYULAI, FERENC
Institute for Wildlife Management
and Nature Conservation
Hungarian University of Agriculture
and Life Sciences
H-2100 Gödöllő, Páter Károly str. 1.
andor20@gmail.com

KOLLÁTH, ÁGNES
Institute of Archaeology,
Research Centre for the Humanities
H–1097 Budapest, Tóth Kálmán utca 4.
kollath.agnes@abtk.hu

KOVÁCS, ÁGNES
King St. Stephen Museum
H–8000 Székesfehérvár, Fő u. 6.
kovacs.agnes@szikm.hu

KOVÁCS, BIANKA GINA
Institute of Archaeology,
Research Centre for the Humanities
H–1097 Budapest, Tóth Kálmán utca 4.
kovacs.bianka@abtk.hu

KOVÁCS, GYÖNGYI
Institute of Archaeology,
Research Centre for the Humanities
H–1097 Budapest, Tóth Kálmán utca 4.
kovacs.gyongyi@abtk.hu

LANGÓ, PÉTER
Institute of Archaeology,
Research Centre for the Humanities
H–1097 Budapest, Tóth Kálmán utca 4.
lango.peter@abtk.hu

MELIS, ESZTER
Institute of Archaeology,
Research Centre for the Humanities
H–1097 Budapest, Tóth Kálmán utca 4.
melis.eszter@abtk.hu

MERKL, MÁTÉ RÓBERT
Kuny Domokos Museum
H–2890 Tata, Öregvár, Váralja út 1-3.
Department of Environmental
and Landscape Geography
Eötvös Loránd University
H-1117 Budapest, Pázmány Péter sétány 1/c.
merkl.mate@gmail.com

MESTERHÁZY, GÁBOR
Hungarian National Museum
H–1088 Budapest, Múzeum krt. 14–16.
mesterhazy.gabor@hmn.hu

NÁDAI, ZSÓFIA
Institute of Archaeology,
Research Centre for the Humanities
H–1097 Budapest, Tóth Kálmán utca 4.
nadai.zsofia@abtk.hu

RÁCZ, TIBOR ÁKOS
Ferenczy Museum Center
H–2000 Szentendre, Fő tér 2–5.
racz.tibor.akos@gmail.com

SCHMIDTMAYER, RICHÁRD
Kuny Domokos Museum
H–2890 Tata, Öregvár, Váralja út 1-3.
schmidtmayer@gmail.com

STIBRÁNYI, MÁTÉ
Hungarian National Museum
H–1088 Budapest, Múzeum krt. 14–16.
stibranyi.mate@hmn.hu

SZILVÁSI, KATALIN JULIANNA
szilvasikatalin05@gmail.com

TAKÁCS, MIKLÓS
Institute of Archaeology,
Research Centre for the Humanities
H–1097 Budapest, Tóth Kálmán utca 4.
takacs.miklos@abtk.hu

ZATYKÓ, CSILLA
Institute of Archaeology,
Research Centre for the Humanities
H–1097 Budapest, Tóth Kálmán utca 4.
zatyko.csilla@abtk.hu

# ABBREVIATIONS

| | |
|---|---|
| AAC | Acta Archaeologica Carpathica (Kraków) |
| ActaArchHung | Acta Archaeologica Academiae Scientiarum Hungaricae (Budapest) |
| ActaMusPapensis | Acta Musei Papensis. A Pápai Múzeum Értesítője (Pápa) |
| Acta Botanica Hungarica | Acta Botanica Hungarica. A quarterly of the Hungarian Academy of Sciences (Budapest) |
| Aetas | Aetas. Történettudományi Folyóirat (Szeged) |
| Agria | Agria. Az Egri Múzeum Évkönyve (Eger) |
| AgrSz | Agrártörténeti Szemle (Budapest) |
| AKorr | Archäologisches Korrespondenzblatt (Mainz) |
| Alba Regia | Alba Regia. Annales Musei Stephani Regis. Az István Király Múzeum Évkönyve (Székesfehérvár) |
| Antaeus | Antaeus. Communicationes ex Instituto Archaeologico (Budapest) |
| AÖ | Archäologie Österreichs (Wien) |
| AR | Archeologické Rozhledy (Praha) |
| ArchA | Archaeologia Austriaca (Wien) |
| Archaeometry | Archaeometry (London) |
| Archeometriai Műhely | Archeometriai Műhely. Elektronikus Folyóirat (Budapest) |
| ArchÉrt | Archaeologiai Értesítő (Budapest) |
| ArchHung | Archaeologia Hungarica (Budapest) |
| Arrabona | Arrabona. A Győri Xantus János Múzeum Évkönyve (Győr) |
| AV | Arheološki Vestnik (Ljubljana) |
| BAR-IS | British Archaeological Reports – International Series (Supplementary) (Oxford) |
| BudRég | Budapest Régiségei (Budapest) |
| Burgen und Schlösser | Burgen und Schlösser. Zeitschrift für Burgenforschung und Denkmalpflege (Heidelberg) |
| Cahiers LandArc | Les Cahiers LandArc (Fleurance) |
| Castrum | Castrum. A Castrum Bene Egyesület Hírlevele (Budapest) |
| CommArchHung | Communicationes Archaeologicae Hungariae (Budapest) |
| Cumania | Cumania. Bács-Kiskun Megyei Múzeumok Közleményei. Acta Museorum ex Comitatu Bács-Kiskun (Kecskemét) |
| Demográfia | Demográfia. Népességtudományi Folyóirat (Budapest) |
| DissPann | Dissertationes Pannonicae (Budapest) |
| DuDolg | Dunántúli Dolgozatok (Pécs) |

| | |
|---|---|
| Építés-Építészettudomány | Építés- Építészettudomány. A Magyar Tudományos Akadémia Műszaki Tudományok Osztályának Közleményei (Budapest) |
| Érem | Az Érem (Budapest) |
| ÉT | Élet és Tudomány (Budapest) |
| Ethnographia | Ethnographia. A Magyar Néprajzi Társaság Folyóirata (Budapest) |
| FMTÉ | Fejér Megyei Történeti Évkönyv (Székesfehérvár) |
| FolArch | Folia Archaeologica (Budapest) |
| FontArchHung | Fontes Archaeologici Hungariae (Budapest) |
| FÖ | Fundberichte aus Österreich (Wien) |
| Föld és Ember | Föld és Ember. Negyedévenkint Megjelenő Tudományos Szemle (Budapest) |
| FrK | Földrajzi Közlemények (Budapest) |
| Geomorphology | Journal of Geomorphology (New York) |
| Gesta | Gesta. Historical Review (Miskolc) |
| Gymnasium | Gymnasium. Zeitschrift für Kultur der Antike und humanistische Bildung (Heidelberg) |
| GySz | Győri Szemle (Győr) |
| Határtalan Régészet | Határtalan régészet. Archeológiai Magazin. A Móra Ferenc Múzeum Régészeti Magazinja. Régészeti Ismeretterjesztő Magazin (Szeged) |
| HungArch | Hungarian Archaeology. E-Journal (Budapest) |
| Hungarian Studies | Hungarian Studies. A Journal of the International Association for Hungarian Studies and Balassi Institute (Budapest) |
| Jahrbuch des RGZM | Jahrbuch des Römisch-Germanischen Zentralmuseums Mainz (Mainz) |
| JAMÉ | A Nyíregyházi Jósa András Múzeum Évkönyve (Nyíregyháza) |
| JAS | Journal of Archaeological Science (London) |
| JCAA | The Journal of Computer Applications in Archaeology |
| KDMK | Kuny Domokos Múzeum Közleményei (Tata) |
| KMMK | Komárom-Esztergom Megyei Múzeumok Közleményei (Tata) |
| Korall | Korall. Társadalomtörténeti Folyóirat (Budapest) |
| KRMK | A Kaposvári Rippl-Rónai Múzeum Közleményei (Kaposvár) |
| LDMK | A Laczkó Dezső Múzeum Közleményei (Veszprém) |
| MatArchSlov | Materialia Archaeologica Slovaca (Nitra) |
| MFMÉ StudArch | A Móra Ferenc Múzeum Évkönyve – Studia Archaeologica (Szeged) |
| MHKÁS | Magyarország honfoglalás kori és kora Árpád-kori sírleletei (Budapest) |
| MittArchInst | Mitteilungen des Archäologischen Instituts der Ungarischen Akademie der Wissenschaften (Budapest) |
| MNy | Magyar Nyelv (Budapest) |
| Múzeumcafé | Múzeumcafé. A Múzeumok Magazinja (Budapest) |

| | |
|---|---|
| Múzeumi Hírlevél | Múzeumi Hírlevél. A Kalocsai Múzeumbarátok Köre Kiadványa (Kalocsa) |
| MRT | Magyarország Régészeti Topográfiája (Budapest) |
| Ókor | Ókor. Folyóirat az Antik Kultúrákról (Budapest) |
| Ősrégészeti Levelek | Ősrégészeti Levelek. Prehistoric Newsletter (Budapest) |
| PA | Památky Archeologické (Praha) |
| PBF | Prähistorische Bronzefunde (München) |
| PNAS | Proceedings of the National Academy of Sciences (Washington, D. C.) |
| Quaternary Int | Quaternary International. The Journal of the International Union for Quaternary Research (Oxford – New York) |
| RégFüz | Régészeti Füzetek (Budapest) |
| Remote Sens | Remote Sensing (Tulsa) |
| Savaria | Savaria. A Vas Megyei Múzeumok Értesítője (Szombathely) |
| SbNM | Sbornik Národního Muzea v Praze Ser. A. (Praha) |
| SlA | Slovenská Archeológia (Bratislava) |
| SMK | Somogyi Múzeumok Közleményei (Kaposvár) |
| SSz | Soproni Szemle (Sopron) |
| Studia Hercynia | Studia Hercynia. Journal of the Institute of Classical Archaeology (Praha) |
| ŠtZ | Študijné Zvesti Arheologického Ústavu Slovenskej Akademie Vied (Nitra) |
| Századok | Századok. A Magyar Történelmi Társulat Közlönye (Budapest) |
| Turul | Turul. A Magyar Heraldikai és Genealogiai Társaság Közlönye (Budapest) |
| UPA | Universitätsforschungen zur prähistorischen Archäologie (Bonn) |
| VAH | Varia Archaeologica Hungarica (Budapest) |
| VMMK | A Veszprém Megyei Múzeumok Közleményei (Veszprém) |
| WMMÉ | A Wosinsky Mór Múzeum Évkönyve (Szekszárd) |
| ZalaiMúz | Zalai Múzeum (Zalaegerszeg) |
| ZbSNM | Zborník Slovenského Národného Múzea. Archeológia (Bratislava) |
| ZfAM | Zeitschrift für Archäologie des Mittelalters (Köln) |

ANTAEUS 39 (2023) 255–278

KÁROLY BELÉNYESY

# SPACES AND SHAPES. POSSIBILITIES OF THE RESEARCH OF HISTORICAL LANDSCAPES WITH LIDAR AND ALS SURVEYS

**Zusammenfassung:** Im Zusammenhang mit der Erforschung mittelalterlicher Regionen kann heute bei weitem nicht mehr nur von jenen Phänomenen gesprochen werden, die über einen ausschließlich landschaftsbildlichen Charakter verfügen, sondern auch über die zusammenhängenden Netzwerke dieser Phänomene, ein System, das wir im Sinne einer Paraphrase des Ökosystems mit Recht als eine Art Anthroposystem bezeichnen dürfen. Hier muss erwähnt werden, dass die forschungsbegleitenden und traditionell auf visueller Beobachtung basierenden Vermessungs- und Datensammlungsmethoden in technischer Hinsicht in ein neues Zeitalter getreten sind. Die Überreste anthropogener Einwirkungen und siedlungsgeschichtlicher Netzwerke konnten und können gerade aufgrund dieser technologischen Neuheiten entdeckt, erläutert und damit interpretiert werden. Trotz Algorithmen, Punktwolken und 3D-Modellen ist jedoch der Gegenstand der Forschung weiterhin unverändert. Die Nutzung von LiDAR, oder mit anderem Namen ASL-Technologie könnte die Aufdeckung der historischen Ebenen menschlicher Intervention in der Landschaft und damit das Verständnis der Wechselwirkung zwischen dem Menschen und seiner natürlichen Umgebung zu neuen Höhen verhelfen.

**Keywords:** historical landscape, geoinformatics, archaeological topography, landscape characterisation, algorithm-based analysis in archaeology

Similarly to the introduction of any new research method, the emergence of the LiDAR or ALS-based analysis of the historical landscape requires developing new terminology and revising already existing terms. Therefore, it is worth to start this paper with a few thoughts about its subject. While overviewing the overwhelmingly abundant literature on the possibilities, international trends, and methods of the characterisation of the historical landscape is beyond the scope of this study, one shall examine the factors determining the meaning of the concept.[1]

According to subsection 1 of section 120 of Act C of 2023 on Hungarian architecture, 'partially built-up landscapes developed jointly by humans and nature, which comprise built and natural cultural heritage elements that are important from a historical, culture-historical, cultural monuments', artistic, scientific, or technological point of view and form a homogenous topographical unit that can be delineated must be considered historical landscapes and placed under monument protection.'

[1] When discussing the concept of historical landscape, the fundamental work by Michael Aston must be mentioned; besides, in Hungarian research, the volumes of the Archaeological Topography of Hungary *(MRT)*, where terrain features considered elements of the historical landscape, have been included at an early point of research, serve as a point of reference *(Aston 1985, MRT 4)*. For diverse conceptual and methodological approaches to the topic, see *Bruno – Thomas 2010,* in the context of the Carpathian Basin, *The Carpathians 2013,* while for an overview of the possibilities of Hungarian research, *Zatykó 2015*.

DOI: 10.62149/Antaeus.39.2023_07

The subsection illustrates well that landscape and its historical layers escape rigid definitions and narrow concepts; no wonder this element has always been the most challenging to fit into heritage protection regulation. It is an outlier amongst archaeology and cultural monument management concepts and has evaded better and less successful attempts to define it. Our planet is deeply affected by anthropogenic effects, and, seen in the perspective of tens of thousands of years, the proportion of virgin areas is extremely low. Whether a distant, centuries-old forest or a crowded urban environment, the landscape around us is far from being untouched but in continuous change. It has its own history with layers and inner contexts and, accordingly, archaeology.

### *The archaeology of the landscape*

The landscape is not an archaeological site in the traditional meaning of the concept as it can be approached, characterised, and described only through some of its characteristic and discernible elements, the investigation of which allows one to analyse the historical landscape. However, some elements of the past landscape (dams, earthworks, burial mounds, traces of cultivation, channels or the remains of the one-time road network) cannot be 'excavated'; thus, their research requires a unique methodology. Instead of delving into the traditional methods of cadastral surveying (discovery, observation, surveying, and description), this study focuses on alternative sensing methods.

Correct classification of available visual information requires the research of the historical layers and inner contexts of the landscape. Simply put, we can only work with what we see; what we fail to observe remains hidden from research. Regardless of the method of data collecting, only those elements become part of the historical landscape we consider to be, independent of whether they really are. Therefore, despite aiming for objectivity, this approach remains highly subjective, even if the one applying it has years of experience in the field or data processing. The researcher is always a factor in the process of interpretation, filtering actively (on field surveys or field collecting trips) or passively (when analysing aerial photos or the results of other geospatial surveys) the information a landscape holds. Searching for the elements of the historical landscape is a kind of clue-tracking, as sometimes the shape, the structure, or the raw materials of a dam, a road, or an earthwork is the key to answering a question about the origin, dating, or function of that particular terrain feature. Whether a tumulus field, a mine, an earthwork, or the special traces left behind by agricultural activity (ploughed fields, plot systems, and farmyards), landscape archaeologists – like trackers – examine the particular phenomenon under study in the context of its ecosystem, while being aware that the reasons behind landscape formation between the Neolithic and Late Medieval times are region- and period-specific.

Yet, the particular identified features can only be interpreted properly as a system, i.e., in the context of each other, and revealing the connections between visible features and those that had vanished from sight by today is an inescapable part of this process. Whether some burial mounds beside a Roman villa farm, the remains of which are hidden from the naked eye or the relation between the ramparts and the settlement part on a Bronze Age fortified settlement, the traces one can detect in the landscape today are all remains of a complex network defined by diverse factors. Therefore, the question is not whether it is worth collecting and analysing such elements, even with a predictive approach, but whether it is possible to recognise patterns unique to a period or a function in the ever-changing landscape. Another important question is, how can we identify in the recent landscape the elements that may belong together; therefore, the quantity of relevant and authenticable data points suitable for analysis is key for structural mapping of the network of complex spatial and temporal relations within the landscape.


Fig. 1. 1. Riegl VP-1 VUX LiDAR laser scanner;
2. Riegl VP-1 VUX LiDAR laser scanner mounted on a helicopter

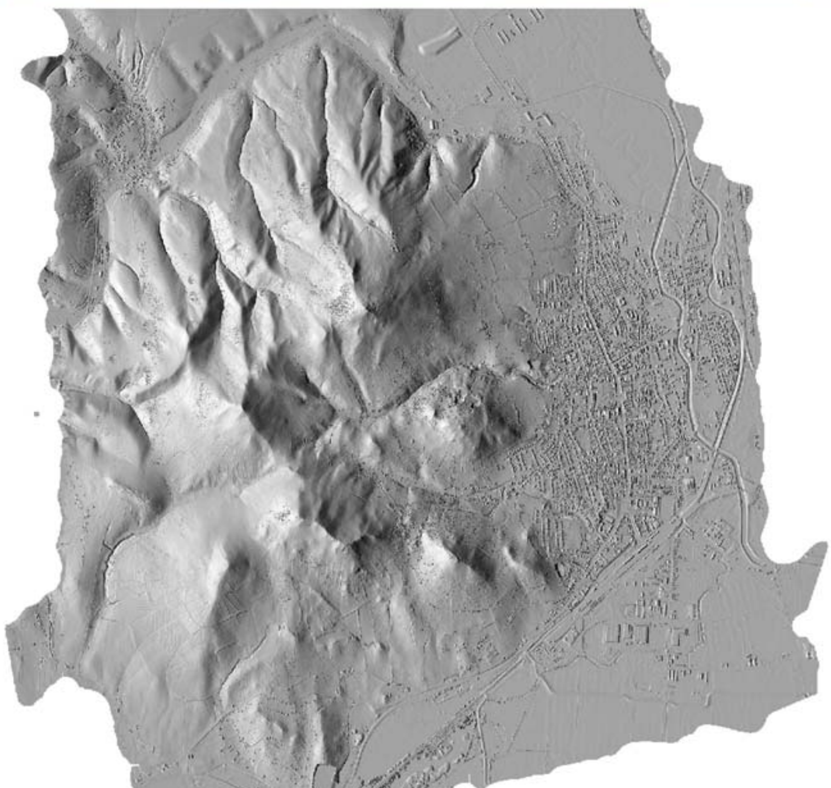
*Objectivity, perceptibility, patterns, and network*

Modern remote sensing methods have been used for some time in the research of historical landscapes; accordingly, archaeologists are generally familiar with the LiDAR technology as well.[2] The acronym is short for a term which basically describes the essence of this method: Light Detection and Ranging. It involves a special kind of data collecting, practically scanning the designated area with millions of laser pulses emitted by devices mounted to a drone, helicopter, or plane flying at low altitudes *(fig. 1)*. Accordingly, the method is often referred to by another acronym, ALS, short for 'Airborne Laser Scanning', which is even more accurate. The current precision laser devices and integrated GPS systems are sophisticated enough to ensure high precision independent of the type of carrier. As the laser scanner emits a huge quantity of beams per second, enough reach the surface even in the densest forest to obtain reliable information about the terrain hidden under the canopy (or other kind of vegetation) – sweeping the surface like the light that filters through the leaves in an old beech forest. This method lets one digitally remove the noise vegetation represents from the data set and create a topographical map of the designated area *(fig. 2)*.[3]

Laser beams do not penetrate the ground but are suitable for collecting data about the surface with a few-decimetre accuracy, which, when being processed with special algorithms, allow one to make visible the variety of surface forms and features that cannot be perceived on the spot. In many cases, the diverse surface forms imply what is under them; these signs are important for the broad view rather than only their micro-environment because these tiny anomalies point to large

[2] *Doneus – Briese 2011; Briese et al. 2012; Juhász – Neuberger 2016; Bertók – Gáti 2014; Gáti 2017.*

[3] *Chase – Chase – Chase 2017;* see also the works of the recently and prematurely passed Damien Evans (e.g., *Evans 2013; Evans 2016;* as a co-author *Cohen – Klassen – Evans 2020*), and for a short popular-scientific overview in Hungarian, *Belényesy 2022*. Besides, several European countries have systematic databases of LiDAR surveys. No such database is available in Hungary yet, but the databases of, e.g., Austria, Denmark, Slovena, Belgium, and Slovakia are free to access. More information at https://landscapearchaeology.org/lidar-data/.

2

Fig. 2. 1. Sátoraljaújhely and its surroundings on a satellite image by Google Earth (taken on 28. 09. 2022.); 2. Digital terrain model (DTM) of Sátoraljaújhely and its surroundings (with the vegetation removed)

systems, without knowing which some layers of the historical landscape remain un- or barely interpretable. Such anomalies may indicate one-time plots, ploughlands, house sites, cemeteries, buildings, villages, roads, fortifications, and channels *(figs. 3–5).*

The processing of aerial and satellite images yielded impressive results in the case of non-forested areas and some particular types of archaeological phenomena (e.g., Roman *villa*s, earthworks, certain types of burial ground); with the application of the LiDAR/ALS technology, new lands became available for research. Albeit aerial photogrammetry offers a variety of models,[4] the LiDAR/ALS technology may bring new possibilities (compared to traditional aerial photography) for the virtual isolation and presentation of the diverse layers of the landscape, as well as for predictive modelling, which involves the automatic recognition and prediction of recurring patterns. With the millions of points recorded during a survey, the landscape can be described and, thus, measured, and the clusters of points reflecting a particular characteristic or determinable attributes can be classified into distinct categories. Therefore, syncing the scanner and the processing software and finetuning them according to the aims of the particular research is pivotal. The goal is to recognise and show as many physical features on the surface as possible, whether the subject of the survey is a prehistoric burial ground, an earthwork, a medieval church, or a battleground. But what is the real use of all that?

The primary expectation set against this method is to capture the changes in the historical landscape and present certain elements – ramparts, ruins, and other surface anomalies – in as good quality as possible. However, scanning is superobjective, which means everything perceivable is measured without any previous consideration. As a result, the raw body of measured data comprises all elements (and their connections) of the historical landscape in their complexity, reflecting all layers and periods merged into a single one. A raw scan contains all perceivable phenomena, and it is a task for researchers to select the significant ones. Two approaches can be tried in the selection process, i.e., the analysis of the extraordinarily complex raw picture *(fig. 6. 1–2).*

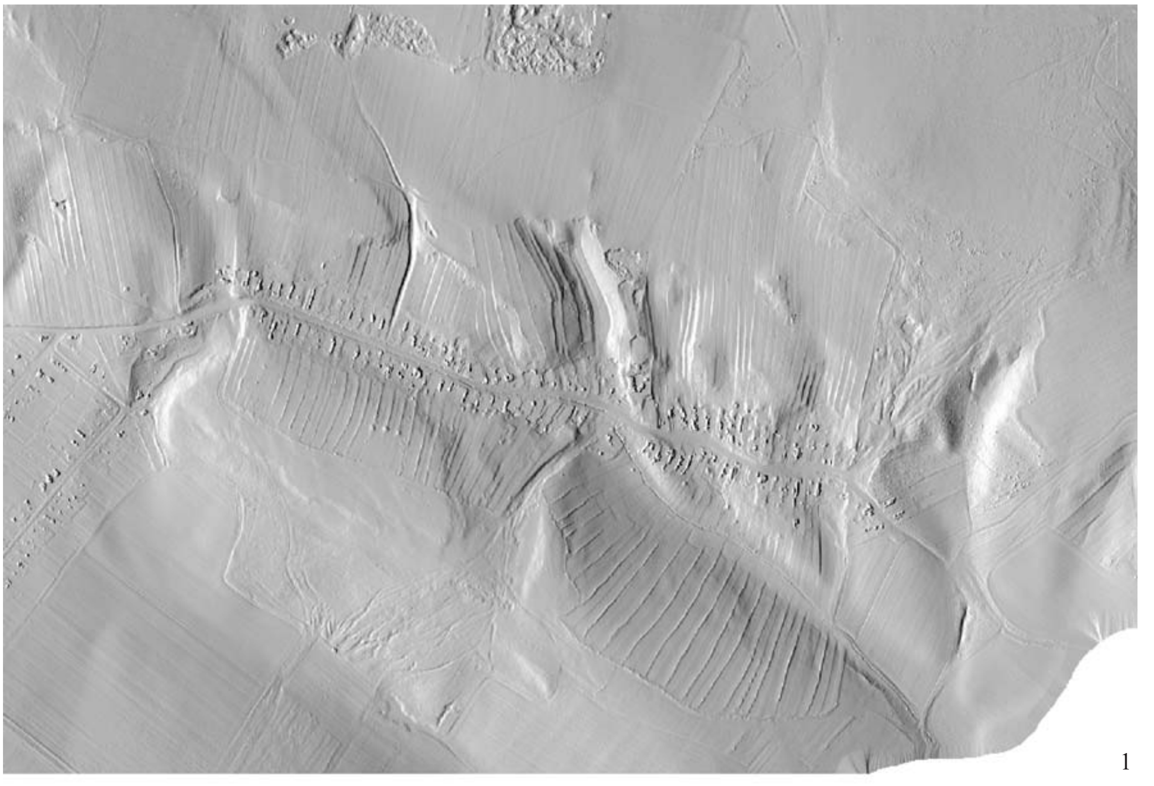
The multitude of data points or point cloud[5] (with the professional term) is suitable for separating the layers, that is, the phenomena of 'historical' interest researchers seek within the obtained body of data. The question is, what 'historical' phenomena are, and how do we label them? One time-consuming but effective way is to isolate and analyse every atypical surface phenomenon one by one. Another possibility is a kind of reverse engineering, when one starts with the elements, connections, and interactions of the historical landscape and removes everything else by omitting first the recognised modern influences and then going back layer by layer, like in an archaeological excavation, removing everything that is modern or belongs to an era different from the one in focus. This ensures that one gets to the original, important details and can properly evaluate the studied historical layers.

The keywords in both cases are modelling and the possibilities of distinguishing between recognised patterns. Identifying a characteristic landmark opens the way to reconstructing the original landscape and the historical environment it incorporates. Such a reconstruction also raises the information value of other archaeological sources, historical maps, and coeval written sources because the information they carry possibly adapts to the original landscape. Some phenomena that, at first sight, seem not particularly significant represent great help in this work as they may

---

4 *Verhoeven 2011; De Reu et al. 2013; Balogh – Kiss 2014; Szabó 2016* 66–75.

5 The point cloud, in this case, is the 'raw' multitude of geospatial data points (actually often resembling a cloud) recorded during a survey. Diverse models can be built from these points of the survey zone. Archaeology usually only uses the data describing the surface; thus, other points retrieved from, for example, houses and trees are considered noise and removed from the cloud during processing. To facilitate their separation, special algorithms can be used that automatically filter out and isolate the points that are unnecessary or noise.



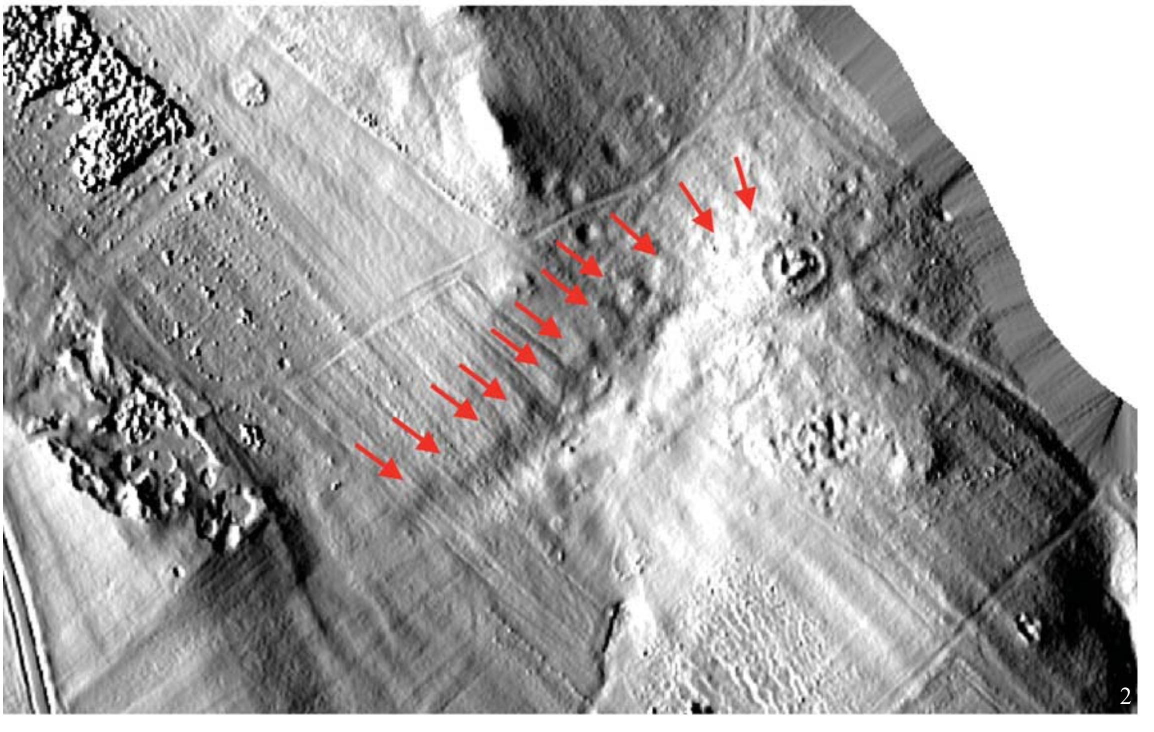




Fig. 3. 1. Historical settlement structure of Lókút. The system of plots and cattle ways is easy to identify; 2. Row of houses along the ‘main street’ southwest of the church in the medieval village of Felső-Pere

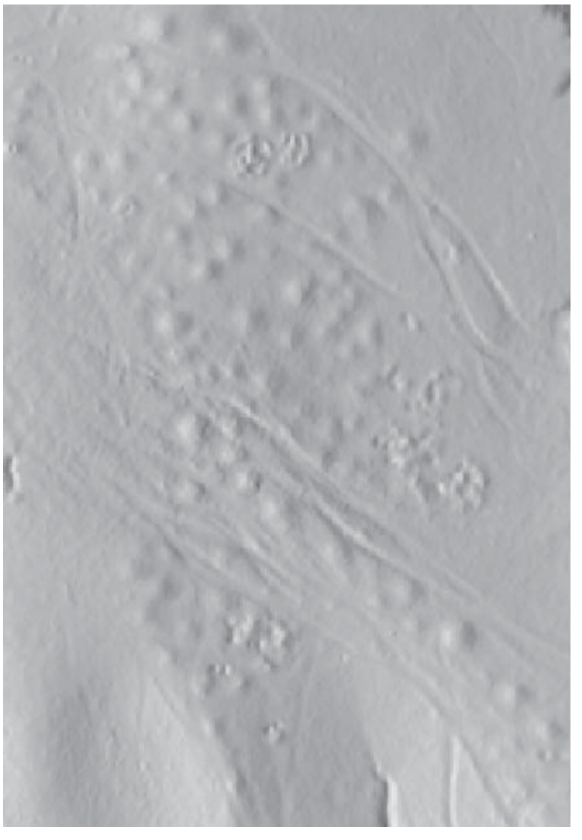


Fig. 4. Detail of the tumulus field at Ugod-Katonavágás II

Fig. 5. Two ramparts of the probably Bronze Age fortification system known as 'the Podmaniczkys' Road' and the unique articulated structure of the inner side of the earthwork identified on the LiDAR survey image of Nagy-Somhegy in Bakonybél

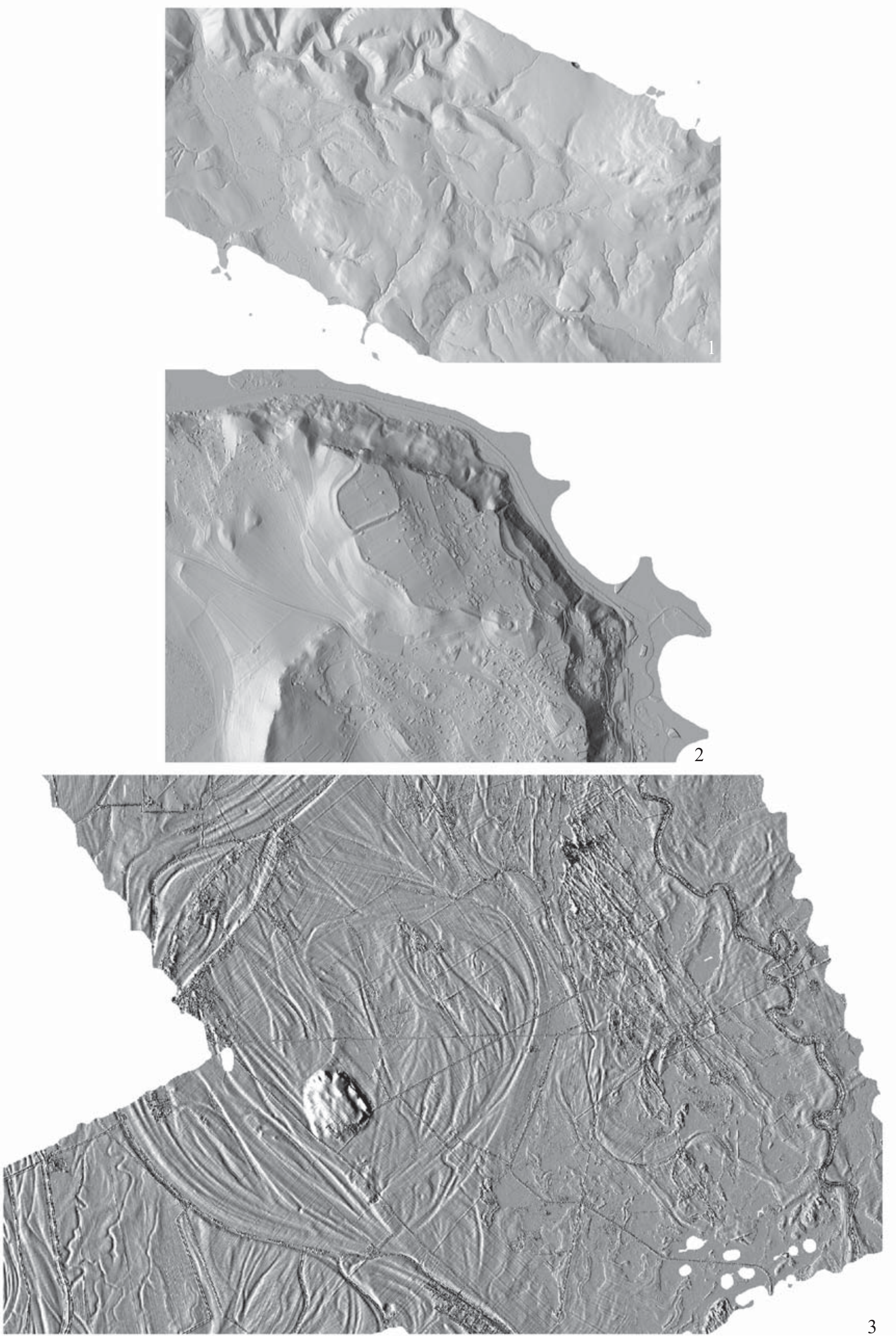



Fig. 6. 1. Grey-shaded digital terrain model (DTM) of Bakonybél and its surroundings (with the vegetation removed); 2. Grey-shaded digital terrain model (DTM) of a detail of the Tihany Peninsula with the Iron Age hillfort and settlement centre (with the vegetation removed); 3. Grey-shaded digital terrain model (DTM) of Solt-Tételhegy (with the vegetation removed)

be especially important when interpreting past events. Such a phenomenon can be a road, an embankment, settlement phenomena, and one-time beds of streams and other watercourses that have vanished by today or become less characteristic elements of the landscape *(fig. 6. 3).*

The historical environment, like the ecosystem of the natural environment (discussed above), can be described as an anthropogenic network with many internal connections. The arrangement where the roots of the trees, the mycelium interlacing the soil, the insects and the animals of the forest act in a symbiosis as a living system can be projected to the anthropogenic environment, too; therefore, by identifying some details, one may improve its understanding of the whole anthroposystem. The differences in the analysis of the two systems lie only in the ways of perception and selection.

### *Limitations of the LiDAR/ALS technology and considerations in planning a survey*

Like with any technology, the keys to success with LiDAR/ALS surveys are adequate research questions, a well-tailored survey method, and accurate planning. The carrier type and the capacity of the scanner are also important. As the emission rate (pulse/second) of the scanner is not constant, the scanning frequency must also be determined after the survey area has been delineated, and with consideration to the intended use as an industrial, environmental management-related, or an archaeological analysis may require different resolutions. Many factors may influence the optimal resolution, including the character and size of the survey zone, the terrain features/landmarks to be surveyed, the time of surveying, and the vegetation. In the vegetation period, low altitude and high frequency give better results, while in other parts of the year – from the falling of leaves to the time when fog shrouds the landscape even at daytime and snow has not fallen yet or just before spring – quite the opposite, higher altitude and lower frequency may be expedient. With an archaeological survey, if the scanner is set to an (average) 600 or 400 kHz frequency, the altitude must be around 170–200 m.[6]

A basic characteristic of the LiDAR/ALS method is that at every setting, higher pulse density comes with lower signal levels, i.e., either one retrieves more but less reliable data (due to less energy) or the opposite, less but more accurate.[7] Obviously, the greatest challenge to overcome when making a survey is vegetation because of the significant data loss due to the diverse layers of the canopy of the trees and the various layers of the vegetation underneath. Albeit vegetation is part of the landscape, it represents unnecessary data (noise) in a survey intended for archaeological use; in this case, scanning on the highest setting does not represent a viable solution due to the characteristic of the method as described above (many less reliable vs few more reliable data points).

When planning a survey, not only the characteristics of the vegetation and the must of securing a suitable signal strength must be taken into account, but also the limiting factor of the terrain and the manoeuvrability of the carrier. It is important how manoeuvrable the carrier (in our case, a helicopter) is at optimal cruising speed: when the terrain is extremely rugged, survey distance

---

6 The presented surveys were made with a Riegl VP-1 VUX LiDAR scanner and realised within the frame of the '*Védett kulturális és természeti örökség távérzékelési technológiai kutatási centrumának létrehozása, új méréstechnikai módszerek és dokumentációs eljárások kidolgozása*' [Development of a remote sensing technology research centre for protected cultural and natural heritage and new survey and documentation protocols] GINOP-2.1.1-15-2015-00695 project.

7 Low energy levels can affect data quality significantly: reduced signal strength results in weaker return signals which may be inaccurate, especially in areas with low reflectivity or dense vegetation. Besides, they may struggle penetrating dense vegetation and have a shorter effective range and, occasionally, fewer return signals. All these contribute to an incomplete point cloud with gaps, inaccuracies, and relatively high noise.

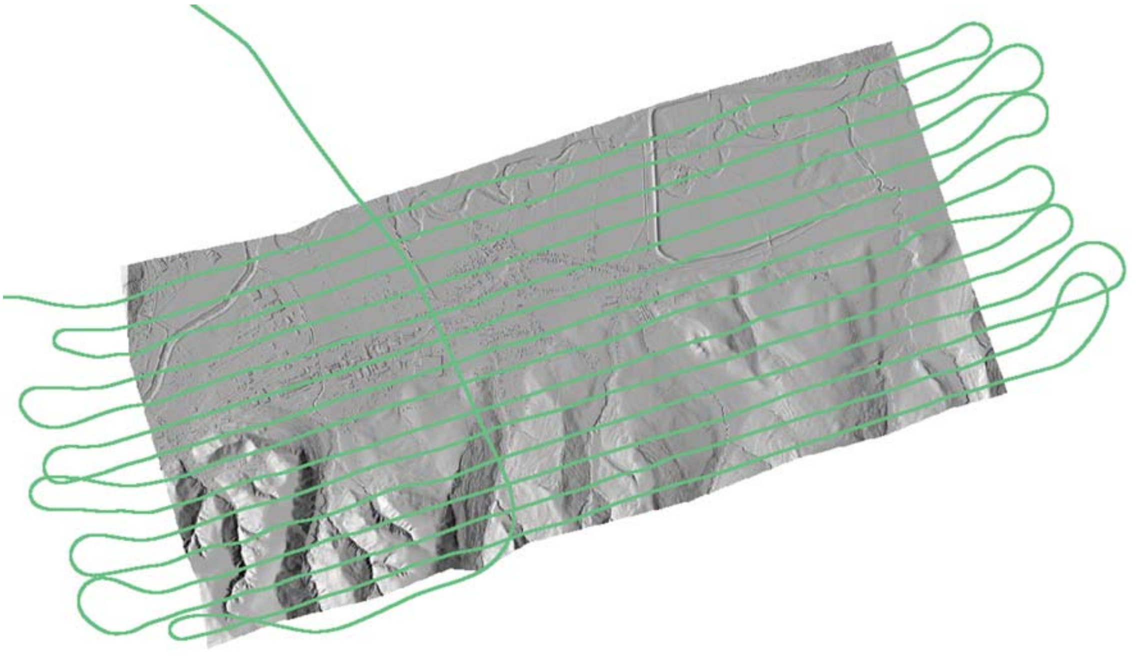


Fig. 7. Survey zone of the Battle of Segesvár with the flight track

decreases when approaching or flying over a steep slope, and the swath (i.e., the width of the coverage area) of the LiDAR scanner decreases with it. Therefore, an experienced pilot may ‘pull up’ the plane, which results in the scanner emitting pulses in directions other than vertical, which causes insufficiently low data density at the foot of the slope. Therefore, the pilot must be careful to keep the plane (and, thus, the mechanical axis of rotation of the scanner) horizontal at all times, partly to ensure equal data density and to prevent the scanner from being unnecessarily exposed to the effects of acceleration *(fig. 7)*.

The flight direction is also crucial; at 20 knots (ca. 7 kph) or higher air motion, the planned footprints must be parallel with the direction of the wind to make holding the path easier for the pilot. When the wind is lower, the most important consideration in planning may be efficiency, that is, optimising the turning path. For example, when the survey zone is rectangular, the turning paths must be planned to parallel the long sides so less of the precious operating time is spent on turning. No data is collected during turning, but the manoeuvre cannot be swift as the scanner is still onboard, and its mechanism must be protected from the effects of acceleration. One must also take account of the main directions when planning the survey of a linear phenomenon (a ditch, an embankment, etc.) and avoid perpendicular paths.

Besides, one must also consider the building density of the survey zone, the peace of the residents, the discomfort caused by noise load, and discomforts caused by systematic flying.

In summary, one base pillar of successful research is careful preparation, that is, a well-designed flight plan that serves as a base for a remote sensing permit request. A flight plan incorporates many other considerations, too, regarding bandwidth settings, angle range, the GPS antenna, the synchronisation of the control measurements on the ground, and the possible effects of fog or a snow-covered surface.

The 170 km path needed to survey an area of approximately 50 km$^2$ can be covered in about 1.5 hours; however, the obtained results will only be suitable for processing if the survey runs according to an adequate plan. Based on trajectory data, the data set, and the data obtained from permanent geodetic points of reference in Hungary, the accuracy of the data obtained is about 20–30 cm. However, the inner consistency of the data points within the set, which is far more

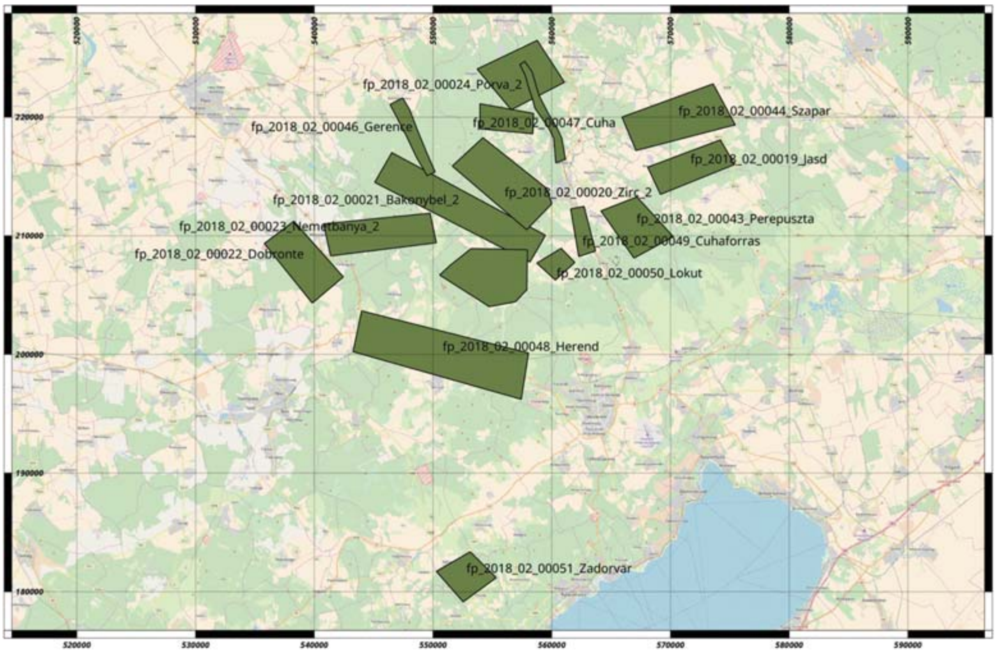



Fig. 8. Designated survey zones in the Bakony Mountains

important for research, is way higher, with a precision of under 1 cm per data point. Conclusively, it is easy to see that not accuracy but resolution is decisive in the quality of a dataset because if only a few pulses/m$^2$ reach the surface, the retrieved data will be way less than if the number of pulses is ten times higher to start with *(fig. 8)*.

### *Data visualisation*

Data visualisation is the answer to the demands of observing and making visible because only the archaeological phenomena that can be visualised are significant for research. However, one must be aware of the characteristics of the technology when forming expectations and understand that the visually readable rendering and the one suitable for analysis are not necessarily identical – the latter may be best compared to the methodology and terminology of ultrasonography (instead of 'traditional' archaeological data collecting methods like field survey or aerial photography). Evaluating the visual rendering (image) might be a challenge, even for an experienced researcher.

Anthropogenic influence can be revealed by filtering the immense quantity of obtained raw data using various methods and algorithms. A real milestone in the development of this field was the publication of a particularly useful handbook by Žiga Kokalj and Ralf Hesse on ALS data processing and visualisation, with descriptions of some characteristic types of phenomenon and how to perceive them and which tools are available for data processing.[8]

More data has yet to be collected to compile a comprehensive handbook about the archaeological LiDAR/ALS surveys of the Carpathian Basin; however, a structured archaeological and/or landscape historical analysis of the available isolated datasets might serve as a basis and proper impetus for the preparation of overviews of particular micro-regions. In the following, previous surveys and, through their examples, important 'partial' results are presented.

[8] *Kokalj – Hesse 2017.*

*Zirc-Tündérmajor*

The surveys carried out in the Bakony Mountains cover hundreds of square kilometres. Besides obtaining a set of systematically collected data from large areas, this survey also demonstrated how sensitive the LiDAR/ALS method can be – as illustrated below through the example of tumuli, a characteristic feature type in the landscape.

In many cases, burial mounds are visible to the naked eye; thus, they can be identified and surveyed. However, the condition and prospects of the tumulus fields differ highly. The ones in densely forested areas are usually relatively intact, endangered only by local forestry works; in contrast, others lay on ploughland or in built-up areas. Accordingly, tumuli are easy to identify in a forest but almost impossible to identify in a cultivated area. However, the LiDAR/ALS survey can detect and make visible anomalies which are barely possible or impossible to observe on the field; therefore, the primary goal of the research in the Bakony Mountains was to explore these perishing or already vanished tumulus fields. The analysis of the microtopographic patterns has revealed the presence of often unknown burial mounds in an advanced state of decay on the outskirts of several modern settlements and pointed out many invisible details of the known fields. The former result is extremely important because not only were new tumulus fields identified, but direct information was also obtained on how endangered they are. The significance of that is easy to comprehend, considering that if a burial mound is almost completely eroded away and hardly visible on the surface, the burial chamber at its centre is probably exposed to the harmful effects of agriculture, and the burials or the grave finds can be near or already scattered on the surface, which requires immediate action.

Another important result of this survey was obtaining complex topographical information on large areas surrounding the tumulus fields; now, we can see the whole, well-defined tumulus field with a complex connection network of clusters of diverse size burial mounds. This overview of their inner system might open a new chapter in the research of tumuli regarding their chronology and the related communities and burial rites. Moreover, the relationship between close tumulus fields and their broader environment can now be analysed in a wider context, a single homogenous base survey, that is, the historical landscape. Based on the above, one can conclude that the LiDAR/ALS technology can bring key changes and a new approach to both research and heritage protection.

The study area near Zirc, a long-known archaeological site, was promising. The eroded burial mounds are situated within the perimeters of the town, at the fringes of the built-up area, thus clearly in danger. The illustrations of the paper presenting the results of the survey are, at the same time, chapters of the research history of the area and demonstrate the conspicuous advantages of a tangible representation of the landscape and the terrain forms as compared to the simple ‘double’ contour line[9] marking the perimeters of the site on a map of the Archaeological Topography of Hungary and the Central Register of Archaeological Sites in Hungary. The survey proved that a tumulus field can be identified even in a ‘noisy’ environment affected by large-scale anthropogenic activity and completed the existing body of related information with new details. As a result, we are certain today that the burial mound cluster is part of a larger system or burial ground, elements of which, in a part stretching long toward the residential area of today’s Zirc, became actually identified and, thus, eligible for protection, by this survey *(figs. 9–10)*.[10]

---

[9] Double (or rather, multiple) site polygons are a feature of the Central Register of Archaeological Sites in Hungary (IVO). It is the result of the unique data management within the system where preventing data loss is a priority and reflects a characteristic of archaeological data collecting, namely that sites may appear on the surface with dissimilar find scatters due to intensive agricultural activity, faulty data recording, or revision. Accordingly, each polygon is recorded independently of the rest, marking the extent of the site at a certain time and reflecting on this characteristic of the applied data-collecting methods.

[10] *Belényesy – Wolf 2024.*

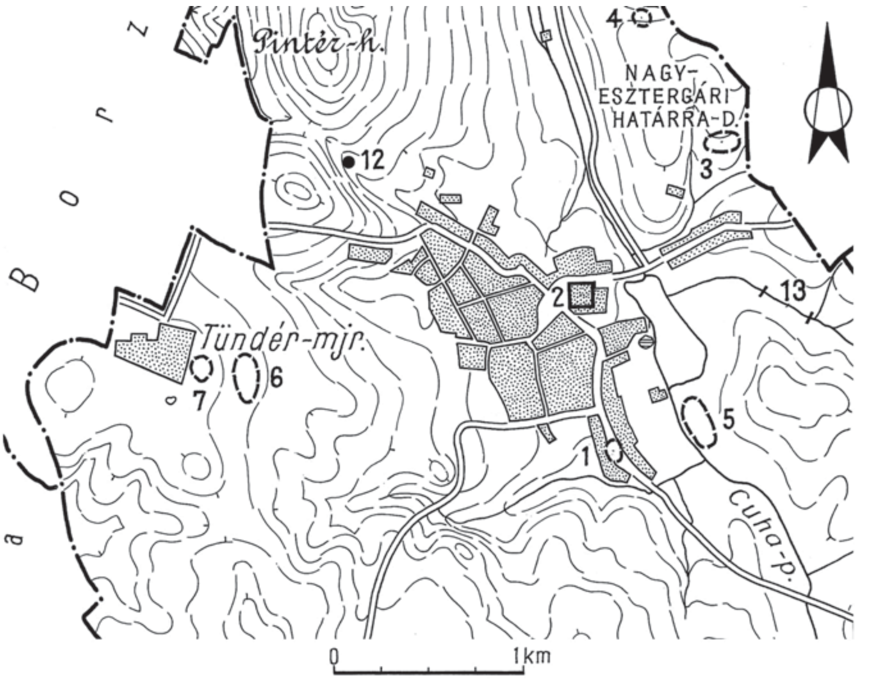



Fig. 9. Zirc-Tündérmajor. Site perimeter polygons on a map of the *MRT 4* 264.

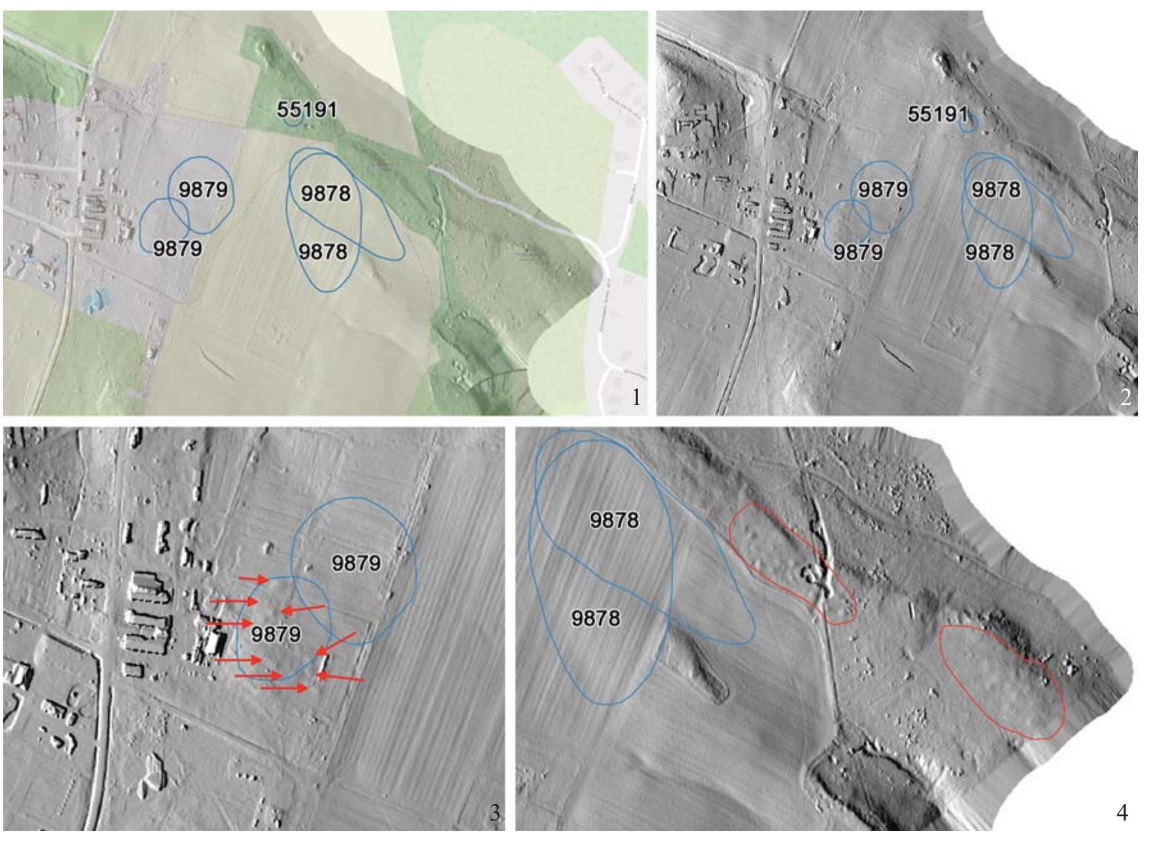



Fig. 10. Zirc-Tündérmajor. 1. Site perimeter polygons from the Central Register of Archaeological Sites in Hungary on a topographic map; 2. Site perimeter polygons from the Central Register of Archaeological Sites in Hungary on a LiDAR image; 3. Known and delineated tumulus field (IVO ID No. 9879). The smaller polygon on the south marks the tumulus field comprising several damaged, eroded mounds. Two tumuli in the south-east are situated outside the registered perimeters; 4. New tumulus fields (red marks), each with ten mounds. The eastern field probably continues towards the area of Zirc

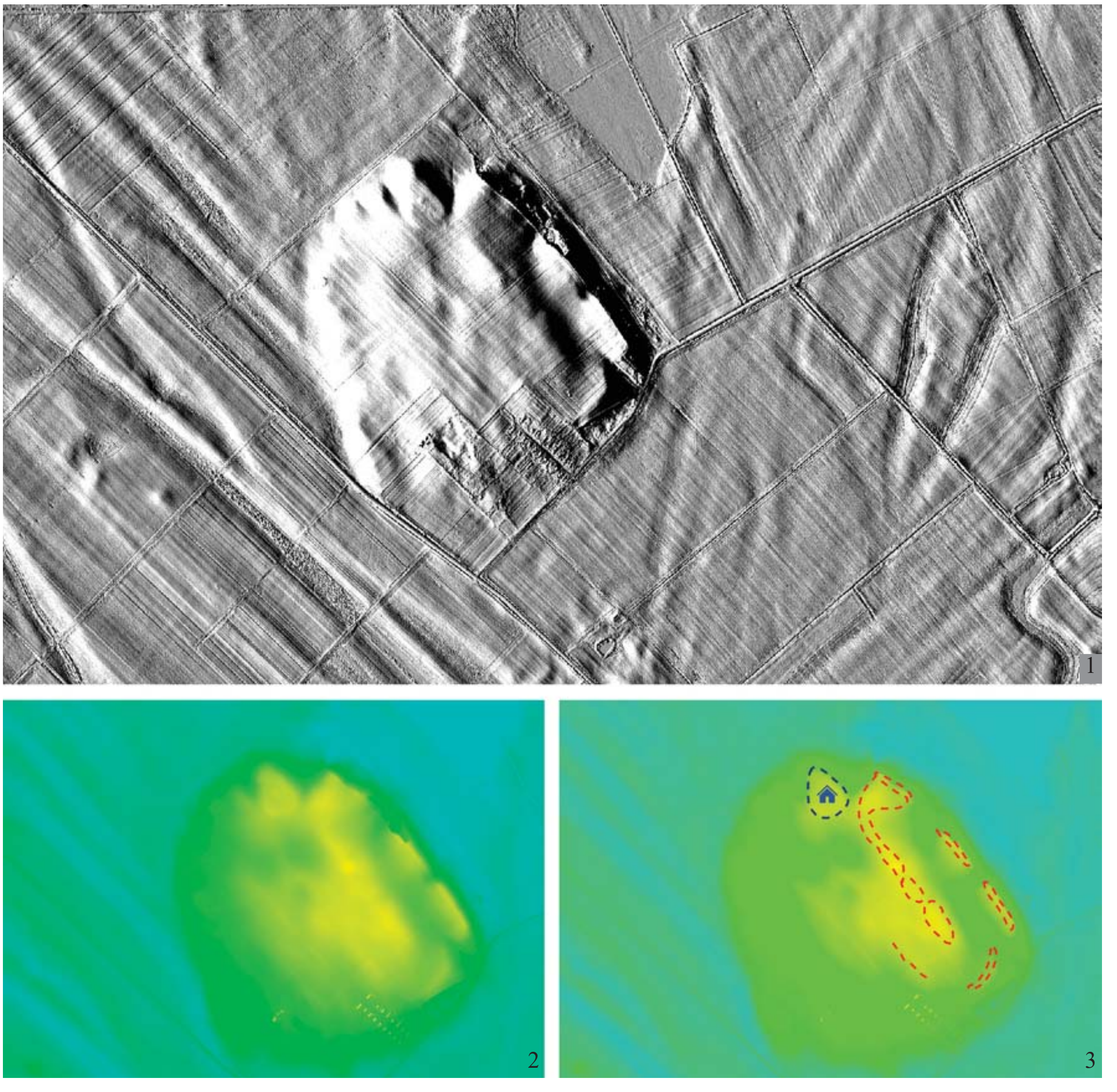


Fig. 11. 1. Grey-shaded digital terrain model (DTM) of Solt-Tételhegy (with the vegetation removed); 2. Colour digital terrain model (DTM) of Solt-Tételhegy (with the vegetation removed); 3. Interpretation of the colour DTM of Solt-Tételhegy with markings of the presumed anthropogenic features, including the separate block of the medieval church in the eastern part

*Solt-Tételhegy*

This site has been subject to intensive investigations and partially excavated. Aerial photography was a crucial part of the survey; combined with recent excavations and a geophysical survey, several historical layers of the plateau could be revealed. One of the most important results of this complex research programme was the identification of a medieval settlement and a system of fortifications on the northern side of Tételhegy.[11] The LiDAR scan corroborated the image compiled from archaeological data; however, some features that appear in the aerial images are not present in the LiDAR terrain model. For example, while the isolated block of the church, the ovoid ditch enclosing it, and some connected elements of the fortification on the northern slope of the hill are clearly discernible, even conspicuous, the southern fringes of the medieval settlement are almost invisible. The intensive ploughing of the area in question, which accelerated the filling of the ditch, can only partially explain this phenomenon *(fig. 11)*.

[11] About interdisciplinary research, see especially *Szentpéteri 2010*.

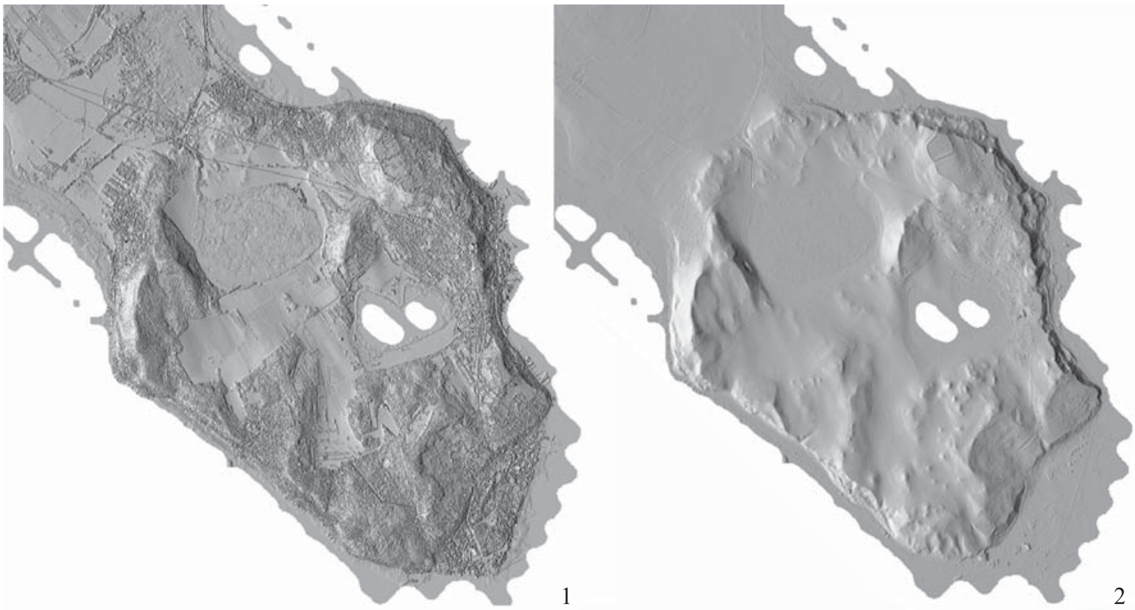



Fig. 12. 1. Digital surface model (DSM) of the Tihany Peninsula (with vegetation); 2. Digital terrain model (DTM) of the Tihany Peninsula (with the vegetation removed)

In contrast, the fortifications at the edge of the plateau of Tételhegy are in fairly good condition. It would be evident to identify these persisting sections as parts of the one-time (probably prehistoric) fortifications protecting the hilltop; however, this hypothesis has to be proven archaeologically. A deeper analysis of the LiDAR-based digital terrain model represents a possibility for a more detailed evaluation because the surface inside the clearly visible edges of the plateau is far from even: the eastern part is definitely higher than the western and southwestern and is articulated in a north-south direction. The rampart (bearing anthropogenic characteristics) is in good condition on the eastern and north-eastern edge of the plateau and turns at the south-eastern corner. The earthwork is interrupted at two points; it cannot be excluded that the two gaps on the eastern side and at the south-eastern corner, respectively, are the remains of the original entrances (gates?). A minor turn in the related part of the rampart may corroborate this theory but does not represent conclusive evidence because of the use of the slope in modern times. A clearly discernible earthwork, running parallel with the rampart on the eastern slope of the hill, connects the line of the south-eastern corner and the oval enclosure of the medieval church; it is crossed by the medieval double ditch, which appears as a marked anomaly and could be identified on aerial images. The results of the micro-terrain analysis suggest that the centre of the plateau and the zone aligned with the rampart system on the eastern slope rise considerably above their surroundings. Based on the relative position of the earthworks, this area, akin to the ovoid block of the medieval church, forms a topographically distinct unit within the plateau.

Many of the detected anomalies are well-visible; they represent a firm base for drawing more general conclusions. By accepting that the detected micro-terrain features (anomalies and zones) like that of the medieval church are marks of historical anthropogenic activities stemming from similar causes and see them as some kind of indicators, the presence of extensive active zones (from a settlement-historical point of view) can be presumed in the area of the earthworks of the eastern slope and the small elevation in their foreground and on the north-eastern side of the valley north-east of the small promontory of the medieval church *(fig. 11)*.[12]

[12] *Belényesy in print.*

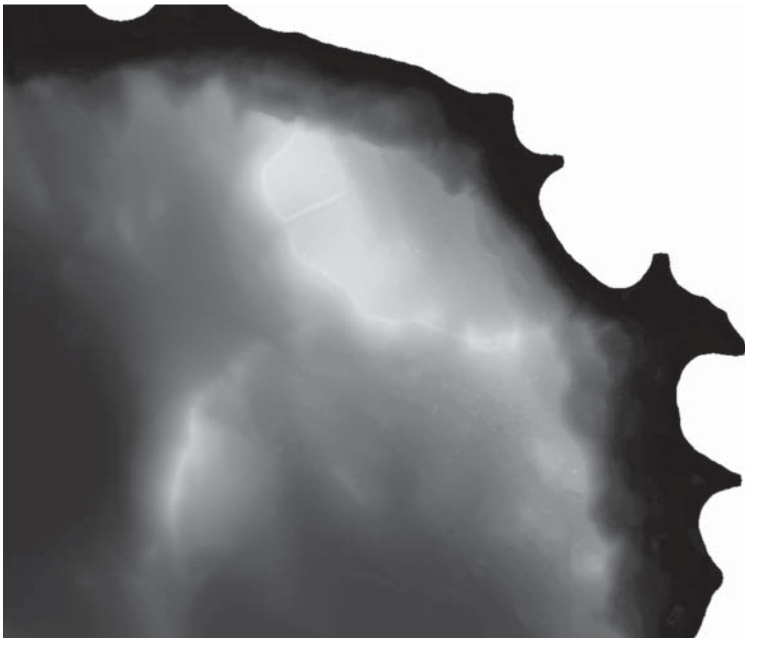


Fig. 13. Analysis of the elevations on the north-eastern side of the Tihany Peninsula. The signals of the high altitude and habitable zones of the Iron Age hillfort and the inner parts have been amplified

The survey of the Tihany Peninsula outlined a similar picture. The analysis of the micro-terrain features of the higher parts of the plateau (suitable for settling) has revealed that the signs of the Iron Age fortified settlement and the medieval anthropogenic zones (that is, the blocks of the prehistoric hillfort and the medieval monastery) form homogenous but clearly distinct, light clusters in the filtered data set. This characteristic pattern differs markedly from the environment, allowing one to suppose that it indicates, like in the previous case, areas which are active from a settlement-historical point of view *(figs. 12–13)*.

*Segesvár (Sighişoara, Romania), battlefield*

The LiDAR technology and strategy applied in the survey of the area where the Battle of Segesvár, the clash concluding the Hungarian Revolution and War of Independence of 1848–1849, took place, do not differ from the method used in the research of any archaeological site – primarily because the goal, reconstructing the historical landscape, was also identical.

The reconstruction of the coeval landscape allows one to place the battle, which took place on 31 July 1849, in its original context *(fig. 14. 1)*. The survey brought to light new details and circumstances which might improve our understanding of how the events unfolded, for example by making visible the riverbed changes of the Nagy-Küküllő (Târnava Mare, Romania), identifying the vanished one-time causeway leading to the castle of Bún (Boiu, Romania), and detecting the traces of supposed cannon fires that showered on the field north-east of Fehéregyháza (Albeşti, Romania) and the Hungarian lines somewhat east of Monostorhegy *(fig. 14. 2–4)*.[13]

The presented examples illustrate excellently that the historical landscape is not only the sum of characteristic terrain features but a complex network incorporating them. Accordingly, the research of the historical landscape is a kind of archaeological topography where visual observations and data collecting occur on a new, higher technological level. But even if relying on algorithms, point clouds and three-dimensional models, the focus of the research remains the same: detecting traces of human activity in the landscape.

[13] *Belényesy – Kuszinger – Kulcsár 2021.*

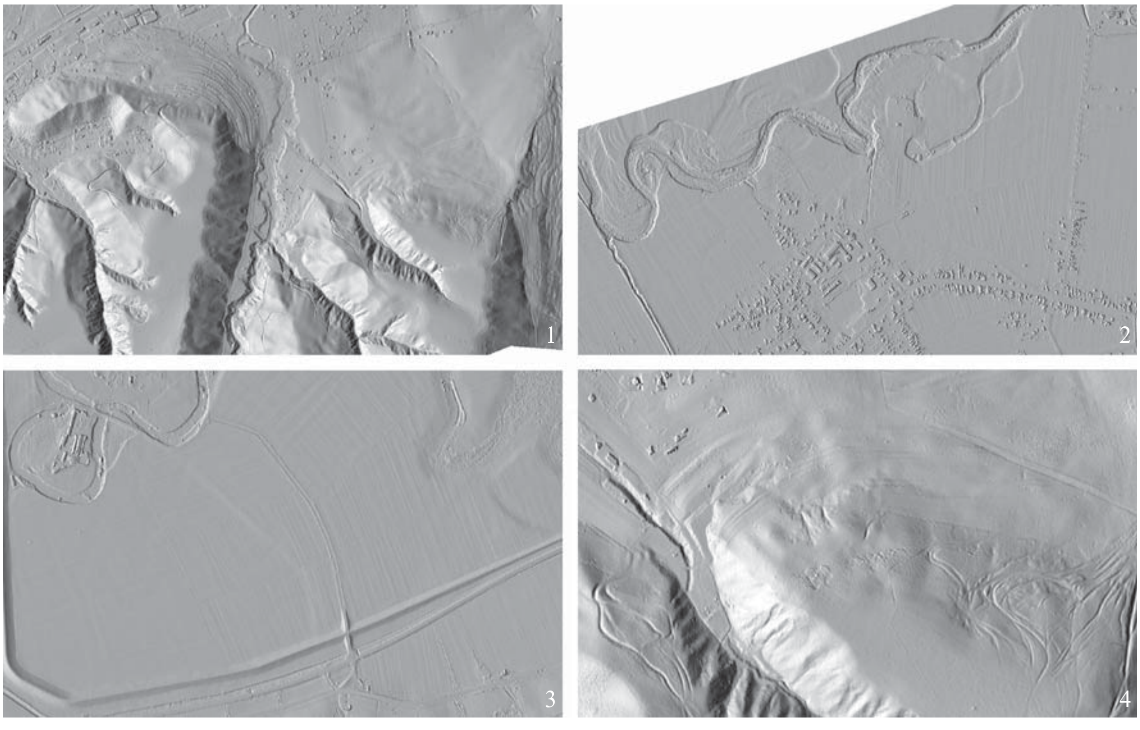



Fig. 14. 1. Southern part of the battlefield at Segesvár (Sighişoara, Romania) on a LiDAR survey image; 2. Riverbed changes of the Nagy-Küküllő north-west of Fehéregyháza (Albeşti, Romania); 3. Road with a slightly broken line at the centre of the digital terrain model. Fehéregyháza (Albeşti, Romania); 4. Supposed position of the Hungarian lines on the LiDAR survey image. Fehéregyháza (Albeşti, Romania)

*Possibilities for development*

As maintaining the objectivity represented by a 'raw' point cloud during processing (that is, isolating the historical layers and transforming them to the visual range) is crucial, this task cannot be burdened on the researcher working with the data set alone but algorithms that may be more precise and can transform terrain features into mathematical formulas and analyse them must also be applied. This way, not only the particular features but also their connections may be revealed and evaluated. Algorithms can do more than merely remove the vegetation: domestic and international examples demonstrate that by using them, one can reconstruct authentic historical landscapes even in areas with extensive plough fields today or heavily affected by forestry. However, such a reconstruction first requires determining the unique characteristics of the possible anthropogenic effects that may influenced the landscape, and the traces of which are still present there, even if in a highly varied stage of perishing. Every terrain feature – a mound, a pit, a depression, an embankment, a dam, a road, or a building – can be broken down to a top point or line (in the case of line features), a bottom point or line, and a slant (the slope of every elevation, depression, and rampart).

By observing simple geometric forms like circles, straight lines, and right angles formed by lines, one can develop processing routine types, which facilitate creating models that can be part of settlement-historical interpretation and highlight the terrain features one is looking for. More complex features can be detected by introducing such routines, which break down every terrain feature into a combination of simple geometric forms. In short, by describing the unique characteristics of the terrain forms we are looking for and translating these descriptions to mathematical formulas, series belonging to terrain features with a settlement-historical relevance might be isolated and identified even in point clouds comprising millions of data points.

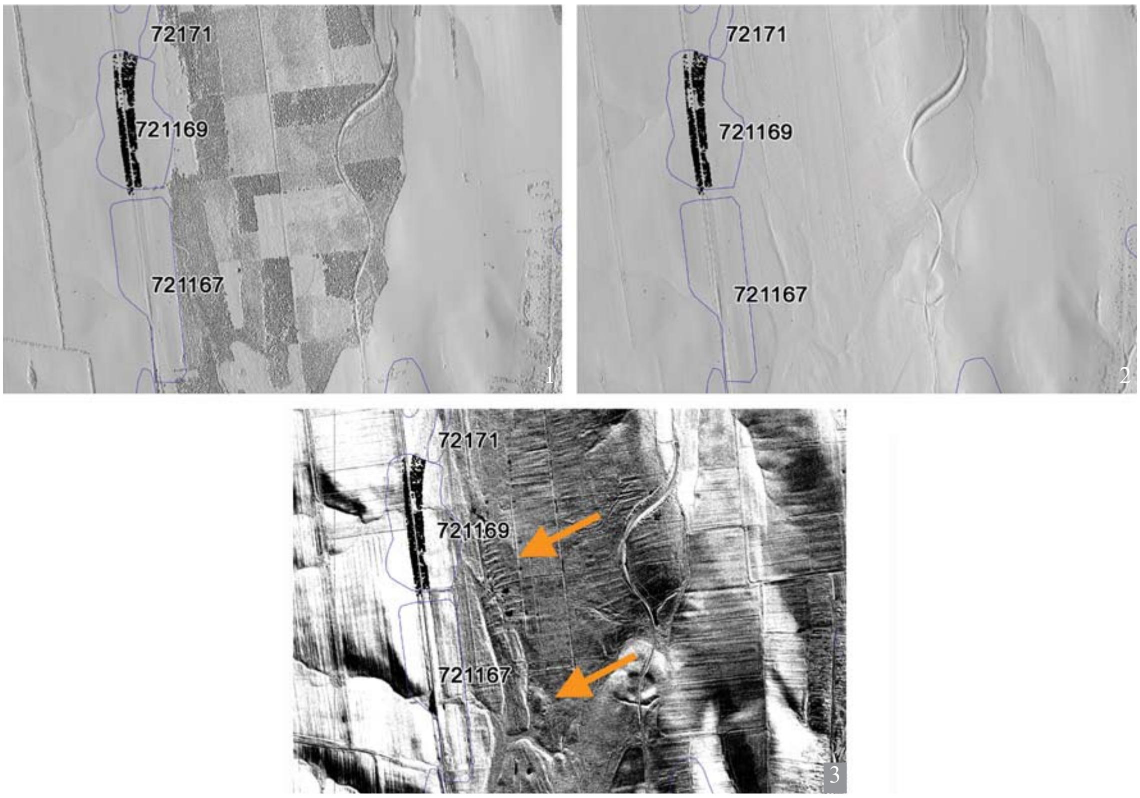



Fig. 15. 1. Digital surface model (DSM) of Gamás-Vadépuszta and its surroundings (with vegetation); 2. Digital terrain model (DTM) of Gamás-Vadépuszta and its surroundings (with the vegetation removed); 3. Pseudo-shaded terrain model of Gamás-Vadépuszta and its surroundings. Arrow marks the amplified signals of the small plots and the centre of the medieval settlement

That would be the next level, but certainly not the last: the world of data transformation, interpolation, signal amplification and attenuation offers countless possibilities for detecting historical layers.

*Gamás-Vadépuszta*

A site that became known for recent excavations was chosen to illustrate the difference between 'traditional' data processing and algorithmic distortion and the advantages of algorithm-based evaluation.[14] The digital surface and terrain models of the survey of the wider area of the preventive excavations preceding the construction of Road 67 demonstrate excellently the possibilities of LiDAR/ALS technology *(fig. 15. 1)*. The long, north-south directed main street of Felsőmocsolád village and the houses accompanying it on both sides are clearly discernible in the south-eastern corner of the digital surface model. The diverse textures of the forests bear no archaeological significance; they mark differences in land use and, perhaps, forestation. The forest patches are usually rectangular, and the anomalies east of the perimeters (as registered in the IVO database) of Site ID No. 72167 indicate an old road. Some line structures are clearly visible outside the forested area, but there is no general characteristic that would help distinguish between modern and old structures.

A system of more line structures could be detected on the shaded digital terrain model presenting the surface without vegetation *(fig. 15. 2)*. Some of the lines clearly mark the borders between differently used pieces of land, ditches, recent streets, embankments, and roads that run

[14] *Belényesy 2020.*

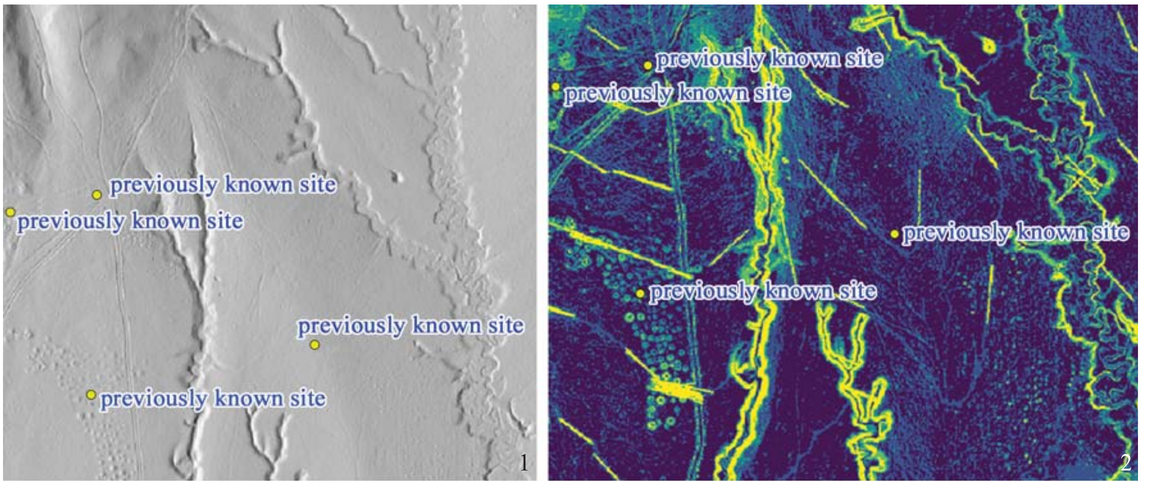



Fig. 16. 1. Digital terrain model (DTM) of Bakony-Százhalom and its surroundings;
2. Cluster analysis of Bakony-Százhalom and its surroundings

in a cut through a terrain form. A regular pattern could be observed east of Site ID No. 72169 and north of a modern forest road: the traces of a former fence and part of the edge of a plot are visible somewhat north-northeast of the big eastern turn of the northern road that runs in the cut. Otherwise, the valley is characterised mainly by north-south oriented line structures (aligning with the direction of cultivation).

The edges, lines, and arheic areas appear highlighted on the pseudo-shaded map of the survey zone, which 'amplifies' micro-anomalies *(fig. 15. 3)*.[15] The rather expressed regular pattern east of Site ID No. 72169 marks one-time plots on the hillside. The 'dark spots' – depressions – within the plots align with the plot system and mark, as the field investigations have confirmed, a former (perhaps medieval) row of cellars. On the same map, a medieval settlement appears south of the plots and cellars on and around a small elevation and the bank of the local stream. Most anomalies on the map are edges, marking the main plough direction and its changes. Traces of small plots can be observed on both sides of the road running in a cut at the eastern edge of the picture. Features indicating division, fences, or stone accumulations may also suggest former plots which were considerably bigger than the ones in the current settlement of Felsőmocsolád.

*Bakony, the so-called Százhalom [Hundred Mounds]*

The Százhalom, a tumulus field in the Bakony Mountains *(fig. 16)*, is a particularly interesting case study, through which the marked differences between the 'normal' and pseudo-shading of a digital terrain model can be illustrated and also how by joining these differently shaded models in a cluster analysis on general settings a new and unique image or pattern of the tumulus field can be obtained.

The examples presented above reveal the possibilities of complex LiDAR/ALS data processing, which offer several prospects for development. The digital environment allows one to model and analyse, besides complex settlement systems and anthropogenic networks, the traces of artificial and natural effects like floods, changes in vegetation cover, or the aftermath of natural disasters.

[15] For more about the pseudo-shading method and the history of its development, see *Kuszinger 2015*. The method was developed within the frame of the realised within the frame of the '*Védett kulturális és természeti örökség távérzékelési technológiai kutatási centrumának létrehozása, új méréstechnikai módszerek és dokumentációs eljárások kidolgozása*' [Development of a remote sensing technology research centre for protected cultural and natural heritage and new survey and documentation protocols] GINOP-2.1.1-15-2015-00695 project.

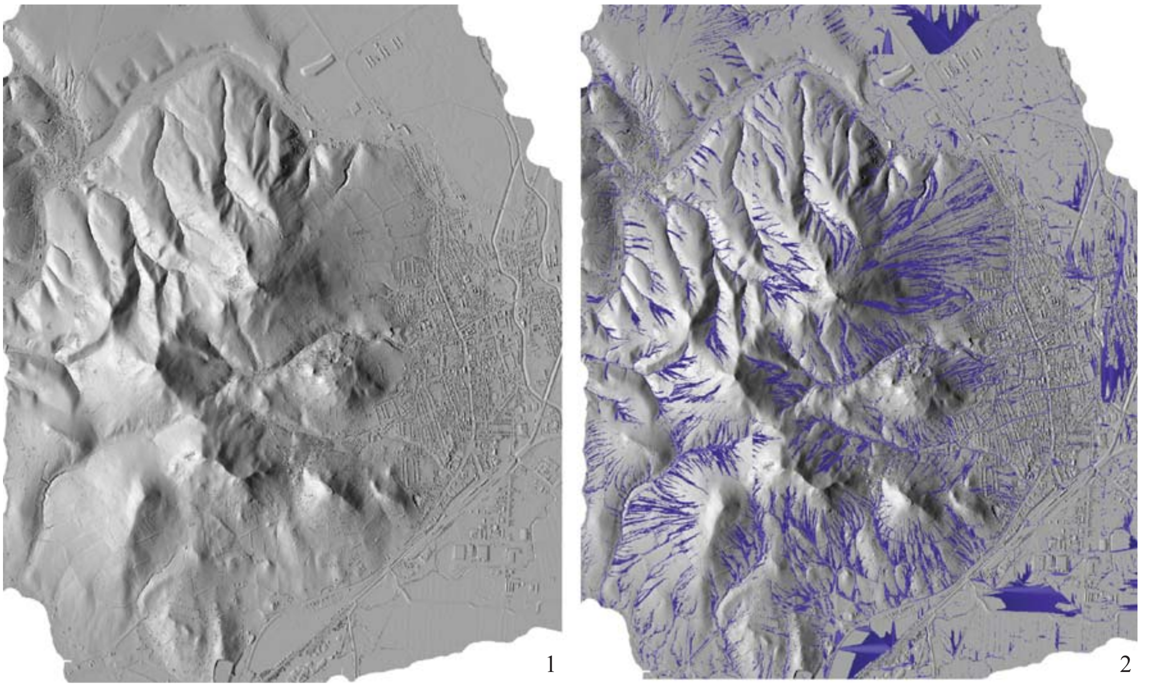



Fig. 17. 1. Digital terrain model of Sátoraljaújhely and its surroundings (with the vegetation removed); 2. Drainage analysis in the digital terrain model (DTM)

In many cases, the broader environment of other networks, ones behind a particular terrain feature or landscape wound (mines, lime kilns, roads, burial mounds, dams, fish ponds, and more) is also worth mapping as they may contribute to determining the specific land use patterns and industrial or trade networks of a particular era *(fig. 17)*.[16]

However, it is also worth going beyond determining diverse filters and processing routines and applying these to the survey zone. Albeit the study by Kokalj and Hesse is a piece of fundamental literature on visualisation tools and the related analytic possibilities, it is perhaps less detailed regarding the unique patterns of particular archaeological features. And yet, determining the archaeological features and the anthropogenic effects connected with them and describing the recurring patterns is the key to progress, to reaching a new level where the authentication of the visual elements and their correlations on field is accompanied by compiling a 'pattern book' of the related features and feature types. Eventually, this would take us to build a new methodology where visually or mathematically described patterns are automatically detected; however, today, in lack of large-scale LiDAR/ALS and field survey campaigns, this path can only be pointed out rather than taken.[17]

## *Conclusions*

Generally, the demand for the application and benefits of impressive high-tech research methods like LiDAR/ALS is no question. However, this technology is much more than a new and spectacular way of data visualisation. It must be understood that the possibilities and sensitivity of the related instruments (for example, a laser scanner) are currently far above any other

[16] *Risbøl – Gustavsen 2019.*

[17] For such initiatives in international academic literature, see *Berganzo-Besga et al. 2021; Guyot – Lennon – Hubert-Moy 2021; Canedo et al. 2023.*

we possess, but that does not mean that ‘conventional’ survey methods must be abandoned – ‘traditional’ archaeological topography and the new technology are not in conflict, and the new possibilities urge for changes in the applied methodology. By joining LiDAR/ALS scanning and the identification of the features on the field, running combined analyses of the obtained data, and building a comprehensive database, archaeology could create a GIS-based base map of the anthropogenic landscape, which integrates archaeological data and their connections and contexts, thus providing an analytic tool that points beyond the cartographic approach.

Another important conclusion is that the fate of the still identifiable and important heritage elements of the historical landscape depends on human actions. Despite the changes in land use patterns and the activities wearing the historical landscape, information can still be obtained on several features that were thought to be lost forever, and organising the available body of information would be essential – it is not an accident that not only national LiDAR/ALS programmes have been initiated in several countries, but the need for worldwide campaigns is also on the agenda.[18]

## REFERENCES


*Aston 1985* M. Aston: Interpreting the Landscape. Landscape Archaeology and Local History. London 1985.

*Balogh – Kiss 2014* A. Balogh – K. Kiss: Photogrammetric processing of aerial photographs acquired by UAVs. HungArch 2014/1, 1–8. https://files.archaeolingua.hu/2014TA/Upload/cikk_Balogh_EN.pdf

*Belényesy 2020* K. Belényesy: Ismeretlen középkori birtokközpont maradványai Vadépuszta határában [Relics of an unknown medieval estate centre in Vádépuszta]. in: Sz. Honti – Cs. Balogh – K. Belényesy – Zs. Gallina – Gy. Gulyás – I. Molnár – P. G. Németh – K. Somogyi – A. Végh: Régészeti kutatások Somogy megyében 2018–2019-ben. KRMK 7 (2020) 217–222. https://doi.org/10.26080/krrmkozl.2020.7.183

*Belényesy 2022* K. Belényesy: Mikrokozmosz a lombok alatt. Gondolatok a LiDAR technológiáról és annak gyakorlati felhasználásáról [Microcosm under the canopy. Reflections on LiDAR technology and its practical applications]. Határtalan Régészet 7/4 (2022) 46–49.

*Belényesy in print* K. Belényesy: Mezítelen táj. A Tételhegy környezetében végzett LiDAR felvételezések ismertetése [Naked landscape. Presentation of LiDAR surveys in the area of the Tételhegy], in: J. Szentpétery (ed.): Castrum Tetel program. Kutatások a solti régióban (2014–2023). *in print*

*Belényesy – Kuszinger – Kulcsár 2021* K. Belényesy – R. Kuszinger – V. Kulcsár: Előzetes beszámoló az 1849. évi segesvári ütközet helyszínén folytatott 2019. évi LiDAR felméréshez [Preliminary report for the 2019 LiDAR survey at the site of the battle of Segesvár in 1849], in: K. Dobás – Zs. Kalla – A. Parádi – D. Tóth (eds.): Kelj föl és járj, Petőfi Sándor! 1848 emlékezete a kultúra különböző regisztereiben. Budapest 2021, 505–512.


[18] *Fisher et al. 2022.*

*Belényesy – Wolf 2024* K. Belényesy – E. Wolf: Bronzkor a lombok takarásában. A LiDAR felmérések szerepe az őskori történeti táj kutatásában [Bronze Age in the shadow of the canopy. The role of LiDAR technology in the research of the őprehistorical landscape], in: G. Ilon (ed.): Asszonyok – férfiak – kapcsolatok. Régészeti tanulmányok a késő bronzkori (Kr. e. 1650/1600 – Kr. e. 800/750) Nyugat-Dunántúl történelméhez. Budapest 2024, 458–462.

*Berganzo-Besga et al. 2021* I. Berganzo-Besga – H. A. Orengo – F. Lumbreras – M. Carrero-Pazos – J. Fonte – B. Vilas-Estévez: Hybrid MSRM-based deep learning and multitemporal Sentinel 2-based machine learning algorithm detects near 10k archaeological tumuli in North-Western Iberia. Remote Sens 13/20 (2021) 4181, Oct. 2021.
https://doi.org/10.3390/rs13204181

*Bertók – Gáti 2014* G. Bertók – Cs. Gáti: Régi idők – új módszerek [Old times – new methods]. Budapest – Pécs 2014.

*Briese et al. 2012* C. Briese – G. Zach – G. Verhoeven – C. Ressl – A. Ullrich – N. Studnicka – M. Doneus: Analysis of mobile laser scanning data and multiview image reconstruction. International Archives of the Photogrammetry, Remote Sensing and Spatial Information Sciences 39/B5 (2012) 163–168.
https://doi.org/10.5194/isprsarchives-XXXIX-B5-163-2012

*Bruno – Thomas 2010* D. Bruno – J. Thomas (eds): Handbook of Landscape Archaeology. Wallnut Creek 2010.

*Canedo et al. 2023* D. Canedo – J. Fonte – L. Gonçalves-Seco – M. Vázquez – R. Dias – T. Do Pereiro – J. Hipólito – F. Menéndez-Marsh – P. Georgiev – A. J. R. Neves: Uncovering Archaeological Sites in Airborne LiDAR Data with Data-Centric Artificial Intelligence. IEEE Access 2023 July.
https://doi.org/10.1109/ACCESS.2023.3290305

*The Carpathians 2013* J. Kozak – K. A. Ostapowicz – A. Bytnerowicz – B. Wyzga (eds.): The Carpathians. Integrating Nature and Society Towards Sustainability. Heidelberg 2013.

*Chase – Chase – Chase 2017* A. S. Z. Chase – D. Z. Chase – A. F. Chase: LiDAR for archaeological research and the study of historical landscapes, in: N. Masini – F. Soldovieri (eds.): Sensing the Past. Geoscience and Sensing Technologies for Cultural Heritage. New York 2017, 89–100.
https://doi.org/10.1007/978-3-319-50518-3_4

*Cohen – Klassen – Evans 2020* A. Cohen – S. Klassen – D. Evans: Ethics in archaeological Lidar. JCAA 3/1 (2020) 76–91.
https://doi.org/10.5334/jcaa.48

*De Reu et al. 2013* J. De Reu – G. Plets – G. Verhoeven – P. De Smedt – M. Bats – B. Cherretté – W. De Maeyer – J. Deconyncs – D. Herremans – P. Laloo – M. Van Meirvenne – W. De Clercq: Towards a three-dimensional cost-effective registration of the archaeological heritage. JAS 40/2 (2013) 1108–1121.
https://doi.org/10.1016/j.jas.2012.08.040

| | |
|---|---|
| *Doneus – Briese 2011* | M. Doneus – C. Briese: Airborne laser scanning in forested areas. Potential and limitations of an archaeological prospection technique, in: D. C. Cowley (ed.): Remote Sensing for Archaeological Heritage Management. Brussels 2011, 59–76. |
| *Evans 2013* | D. Evans: The archaeological landscape of Koh Ker, Northwest Cambodia. Bulletin de l'École française d'Extrême-Orient 97–98 (2010–2011) 91–150. https://doi.org/10.3406/befeo.2010.6130 |
| *Evans 2016* | D. Evans: Airborne laser scanning as a method for exploring long-term socio-ecological dynamics in Cambodia. JAS 30 (2016) 1–12. |
| *Fisher et al. 2022* | C. Fisher – S. Leisz – D. Evans – D. H. Wall – K. Galvin – M. Laituri – G. Henebry – J. Zeidler – J. C. Fernandez-Diaz – S. Pallickara – S. Pallickara – T. Garrison – F. Estrada-Belli – E. Neves – K. Reese-Taylor – R. Opitz – T. Lovejoy – W. Sarni – R. Solinis – G. Ellis – M. Carvalho – C. White – L. Daggars – R. A. Gasson-Pacheco – A. Bolaños – V. Scarborough: Creating an Earth Archive. PNAS 119 (11) e2115485119. https://doi.org/10.1073/pnas.2115485119 |
| *Gáti 2017* | Cs. Gáti: The potential of Airborne Laser Scanning (ALS) in archaeological investigations at Jakab-hegy, Pécs, Southern Hungary. HungArch 2017/3, 11–20. https://files.archaeolingua.hu/2017O/Upload/Gati_E17O.pdf |
| *Guyot – Lennon – Hubert-Moy 2021* | A. Guyot – M. Lennon – L. Hubert-Moy: Objective comparison of relief visualisation techniques with deep CNN for archaeology. JAS Reports 38 (2021) 103027. https://doi.org/10.1016/j.jasrep.2021.103027 |
| *Juhász – Neuberger 2016* | A. Juhász – H. Neuberger: Remotely sensed data fusion in modern age archaeology and military historical reconstruction. The International Archives of Photogrammetry, Remote Sensing and Spatial Information Sciences 41-B5 (2016) 281–286. https://doi.org/10.5194/isprsarchives-XLI-B5-281-2016 |
| *Kokalj – Hesse 2017* | Ž. Kokalj – R. Hesse: Airborne Laser Scanning Raster Data Visualizations. A Guide to Good Practice. Prostor 14. Ljubljana 2017. https://doi.org/10.3986/9789612549848 |
| *Kuszinger 2015* | R. Kuszinger: Lidar data application at Koh Ker, in.: R. Kuszinger (ed.): Koh Ker Project. Annual Report 2015. Budapest 2015, 81–104. |
| *MRT 4* | M. Dax – I. Éri – S. Mithay – Sz. Palágyi – I. Torma: Veszprém megye régészeti topográfiája 4. A pápai és zirci járás [Archaeological Topography of Veszprém County 4. The Pápa and Zirc District]. Magyarország Régészeti Topográfiája 4. Budapest 1972. |
| *Risbøl – Gustavsen 2019* | O. Risbøl – L. Gustavsen: Mapping early iron production features in woodland using remote sensing techniques. Transactions of The Royal Norwegian Society of Sciences and Letters 2019/2, 35–56. |
| *Szabó 2016* | M. Szabó: Archaeology from above. Episodes from the History of the Archaeological Archive of Pécs. Budapest 2016. |

*Szentpéteri 2010* J. Szentpéteri: Interdiszciplináris kutatások a Bács-Kiskun megyei Solt, Tételhegy lelőhelyen. Beszámoló a Castrum Tetel Program (2007–2009) főbb eredményeiről – Interdisciplinary investigations at the Solt, Tételhegy site in Bács-Kiskun county. Report on the main results of the Castrum Tetel project (2007–2009), in: J. Kisfaludi (ed.): Régészeti kutatások Magyarországon 2009 (Archaeological Investigations in Hungary 2009). Budapest 2010, 53–80.

*Verhoeven 2011* G. J. J. Verhoeven: Taking computer vision aloft. Archaeological three-dimensional reconstructions from aerial photographs with photoscan. Archaeological Prospection 18 (2011) 67–73.
https://doi.org/10.1002/arp.399

*Zatykó 2015* Cs. Zatykó: People beyond landscapes. Past, present and future of Hungarian landscape archaeology. Antaeus 33 (2015) 371–390.

ANTÆUS