From Air Survey to GIS-Aided Mapping, Photogrammetry-Based 3D Modelling and the Virtual Reconstructions of Czech Lowland Crop-Marked Archaeological Sites

Od leteckého průzkumu a mapování k tvorbě digitálního výškopisného modelu a 3D virtuálních rekonstrukcí lokalit identifikovaných prostřednictvím porostových příznaků v nížinných oblastech Čech

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In this paper we want to present how data acquired in the 25 years long period during aerial archaeological survey – carried out by the Prague Institute of Archaeology, Czech Academy of Sciences – of buried sites seasonally displayed through cropmarks have recently been processed in order to become a type of document of the same value as the documents produced by means of archaeological excavation, i.e. large scale maps and plans of the detected and photographed crop-marked sites. A principal attention is given to the application of modern methods of 3D modelling. Representative examples are gradually selected from several hundred archaeological sites hidden beneath the earth's surface and seasonally visible through 'vegetation/crop marks' in order to document the potential of such marks to get an idea of the layout of detected sites (individual features as well as complex settlement areas). A 'flight' over a virtual prehistoric or historical landscape in the form of animated video clips can then present in an attractive way, especially to the general public, the characteristic features of the past landscape.

aerial photographs – archaeological remote sensing – cropmarks – photogrammetry – digital surface models – 3D virtual reconstructions

V této práci přinášíme informace o tom, jakým způsobem jsou v současnosti zpracovávána data získaná během 25 let trvajícího letecko-archeologického průzkumu, dlouhodobého výzkumného programu, uskutečňovaného v pražském Archeologickém ústavu AV ČR. Heuristická fáze programu byla založena na identifikaci a fotoletecké dokumentaci pod povrchem terénu ukrytých objektů/lokalit, které jsou za příhodných podmínek zviditelňované prostřednictvím vegetačních příznaků. V posledních letech probíhá zpracování získaných dat do podoby stejného druhu dokumentů, které jsou pořizovány během terénních výzkumů odkryvem – tedy map velkého měřítka a plánů lokalit objevených výše uvedeným způsobem. Velký význam má v tomto procesu aplikace moderních postupů tvorby 3D modelů. Z několika set archeologických lokalit jsou postupně vybírány příklady, na nichž lze dokumentovat potenciál vegetačních příznaků pro získání představy o půdorysu detekovaných lokalit. „Průletem" nad virtuální krajinou formou animovaných klipů lze zejména široké veřejnosti přiblížit charakteristické rysy pravěké či středověké krajiny.

letecká fotografie – archeologický dálkový průzkum – vegetační/porostové příznaky – fotogrammetrie – digitální výškopisný model – 3D virtuální rekonstrukce

1. Introduction

Over the past 30 years, a research programme based on the collection of data from cropmark-based aerial reconnaissance, geophysical measurement, field-walking survey, environmental analysis and test excavations in lowlands and large river basins (i.e., in the most densely populated settlement zones) in Bohemia (the western part of the Czech Republic), situated directly in the heart of Europe, has been systematically performed by the Institute of Archaeology of the Czech Academy of Sciences in Prague (IAP). The recent processing of the data allowed their integration, leading to a better understanding of Bohemia's landscape history. Since 2014, aerial photographs of detected sites (ranging in age from the Neolithic up to the 20th century) have been analysed and their archaeological content interpreted, orthorectified, georeferenced and transformed into a GIS-aided digital map (in vector shapefile format).

The transformation of analysed and interpreted aerial photographs taken during active (i.e. carried out by archaeologists from low flying aircraft) aerial survey to detailed plans of individual sites can undoubtedly be considered the most important step in the process of their evaluation. This is meant both in terms of the care for archaeological heritage, and with regard to the data application in research. It is this approach that increases the potential of discoveries made through active aerial survey, and through which the IAP's archive of aerial photographs (taken between

Fig. 1. *A detailed view to the south-west corner of a crop-marked military (artillery) base perimeter ditch (wide line) and a parallel palisade trench (thin line) constructed in 1813. Due to a right timing of the photograph (June 2011 early morning) the relocation of the palisade trench from the internal side of the camp to the outer side of the ditch is well discernible (Poplze, distr. Litoměřice; see also Fig. 18a). All aerial photographs in this article were taken by M. Gojda. —* ***Obr. 1.*** *Detailní pohled na porostovými příznaky zviditelněné jihozápadní nároží obvodového příkopu polního opevnění typu rohy/hornwerk (širší linie) a paralelního palisádového žlabu (tenká linie) z roku 1813. Díky správnému načasování pořízení snímku (červen 2011 ráno) je dobře patrné, že od nároží fortu byla linie palisádového žlabu přemístěna z vnitřní strany příkopu za jeho stranu vnější (Poplze, okr. Litoměřice; viz též obr. 18a). Autorem všech leteckých fotografií v tomto článku je M. Gojda.*

1992–2016 during annual aerial survey campaigns) is now being processed.

Recently, assorted prehistoric, medieval, postmedieval and industrial sites revealed by cropmarks began to be re-photographed from drones in the high vegetation season (in May–July each year since 2018). Large collections of images then make it possible to produce photogrammetry-based digital surface models (DSM) of these sites and create video clips displaying virtual flights over the landscape with prehistoric villages, fortified sites, cemeteries, military field installations and other similar locations indicated by cropmarks. Finally, these DSMs serve as the foundation for the production of 3D reconstruction models of buried sites and relics based exclusively on the evidence from cropmarks capable of displaying, in some cases, construction details that one would expect to be achievable only by means of excavation (*Fig. 1*).

On one hand, for professional archaeologists we consider these models an important format to illustrate the potential of remotely sensed/detected archaeological remains completely hidden beneath the surface in a way that is non-invasive and, at the same time, has the ability (under certain conditions) to display the precise ground plans of a variety of buried sites of any age and complexity. On the other hand, the processing of gathered aerial photos (both oblique and vertical) into the animated 3D reconstruction models has the potential to offer non-professionals an idea of how to read the landscape memory exposed to current observers via clusters of points and lines of cropmarks in cultivated fields. Consequently, we understand the double potential of 3D reconstruction modelling applied to 'invisible' archaeological heritage as something that should encourage scholars to pay closer systematic attention to the analyses, processing and interpretation of remotely acquired (sensed, evidenced) data, and as a method with the potential to raise the general public's interest in human history – ancient as well as recent.

2. Vegetation/crop marks as an expression of landscape memory

We can understand vegetation marks as an explicit manifestation of landscape memory. Perhaps no other phenomenon has (with the necessary conditions) such an ability to allow us, without our active involvement, to look into the past of the cultural landscape and see traces of the settlement, burial, military or ritual activities of our ancient and recent ancestors and to literally come face to face with our settlement history. Such a window allows us to look into what frequently appears as a tangle of features ('palimpsest') in plan form, as they were created, used and eventually abandoned by their creators in the researched landscape sample in a millennium process, and it is now up to our abilities and modern research to understand and interpret them and determine how to date the individual layers of this palimpsest (*Fig. 2*).

The significance of vegetation marks has been acknowledged in archaeological investigation since the beginning of aerial archaeology; their impact on records of the immovable component of archaeological heritage (sites either buried beneath the surface or preserved in the terrain relief in the form of earthworks) and on the creation of archaeological maps was rated in the past (*Maxwell /ed./ 1983*) and to this day as indispensable (*Verhoeven – Cowley – Traviglia /eds./ 2021*; *Gojda 2020a*; *Tapete /ed./ 2019*; *Luo et al. 2019a*; *Opitz – Herrmann 2018*; *Forte – Campana /eds./ 2016*). It should be emphasised that the information collected on immovable archaeological heritage by remote sensing methods has different characteristics compared to traditional methods of obtaining knowledge. First of all, it is a georeference of the identified components (preceded by their orthorectification), which is mostly due to the clearly visible boundary between the height and colour of crops growing above the ground plans of buried features and outside them (*Fig. 3*) precisely identifiable either in geographical coordinates or in a planar coor-

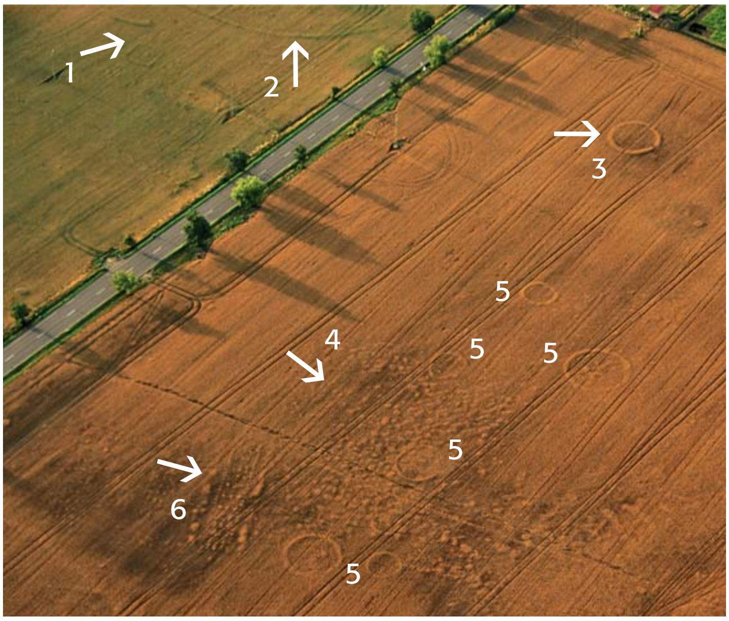

__Fig. 2.__ Crop-marked landscape/settlement palimpsest (Litoměřice region in NW Bohemia). Settlement relics are interpreted as follows: __1__ – small rectangular enclosure with a grave pit placed in its centre (right to the arrow point) and a short ditch placed in front of the feature 2 entrance (left to the arrow point); __2__ – rounded corner of a ditched enclosure dated to the Early Eneolithic (first half of the 4th millennium BC); __3__ – circular ditched enclosure of a ploughed-out prehistoric barrow with an entrance gap; __4__ – cluster of prehistoric storage and waste pits; __5__ – circular ditched enclosures of ploughed-out prehistoric barrows; __6__ – ground plan of an Early Neolithic long house (second half of the 6th millennium BC) with well discernible internal space arrangement through lines of post holes; another two (less discernible) ground plans are situated to the left of the numeral '6'. — __Obr. 2.__ Porostovými příznaky zviditelněný krajinný/sídelní palimpsest (Litoměřicko). Jednotlivé sídelní relikty interpretujeme následovně: __1__ – malé pravoúhlé ohrazení s centrálně umístěnou hrobovou jámou (vpravo od špice šipky) a krátký příkop umístěný před vstupem do objektu 2 (vlevo od špice šipky); __2__ – zaoblené nároží příkopového ohrazení ze staršího eneolitu (1. pol. 4. tisíciletí př. Kr.); __3__ – kruhové příkopové ohrazení zaniklé pravěké mohyly se vstupním přerušením; __4__ – shluk pravěkých (zásobních, odpadních) jam; __5__ – kruhová příkopová ohrazení zaniklých pravěkých mohyl; __6__ – půdorys dlouhého neolitického domu (2. polovina 6. tisíciletí př. Kr.) s dobře patrným členěním jeho interiéru řadami sloupových jam; méně zřetelné půdorysy dalších dvou domů jsou patrné vlevo od číslice „6".

dinate system (the English scholar W. Stukeley described in the first half of the 18th century his observations at Great Chesterford in Essex, South England: '*[...] the proper vestigial of a Temple, as easily discernible in the corn as upon paper. The poverty of the corn growing where the walls stood, defines it to such a nicety, that I was able to measure it with exactness enough.*'; *Wilson 1996*, 42). These components can be analytically

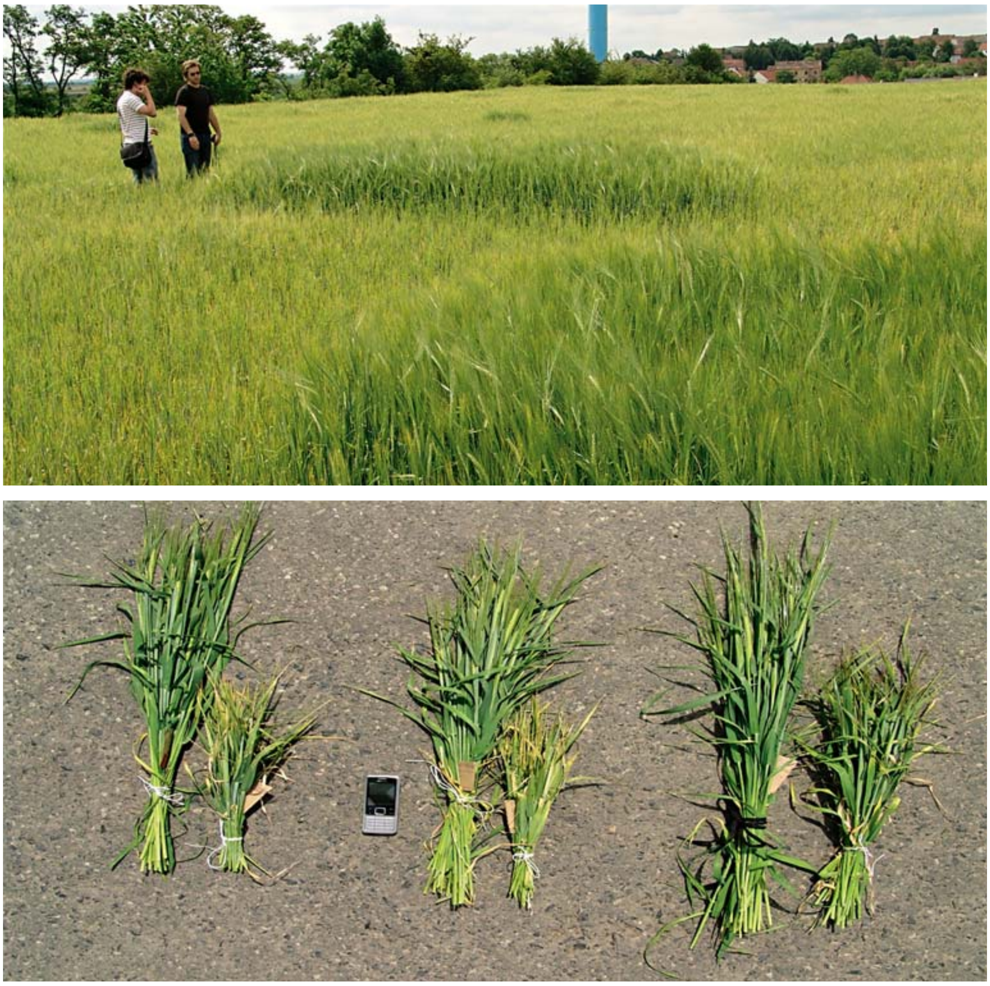

__Fig. 3.__ Difference in the height of barley (in the green phase of its vegetation cycle) growing over sunken huts (top image) dated to the Roman/Migration period (3rd–5th century AD) and away from them (Račiněves, distr. Litoměřice; see chapter 6). As it is apparent in the bottom image, plants growing over the huts can be up to twice as high as plants growing away from them. — __Obr. 3.__ Rozdíl ve výšce ječmene (v zelené fázi vegetačního cyklu) rostoucího nad zahloubenými chatami (horní snímek) z doby římské / stěhování národů (3.–5. stol. po Kr.) a mimo ně (Račiněves, okr. Litoměřice; viz kap. 6). Jak je patrné u příkladů na dolní fotografii, plodiny rostoucí nad chatami mohou dosáhnout téměř dvojnásobné výšky.

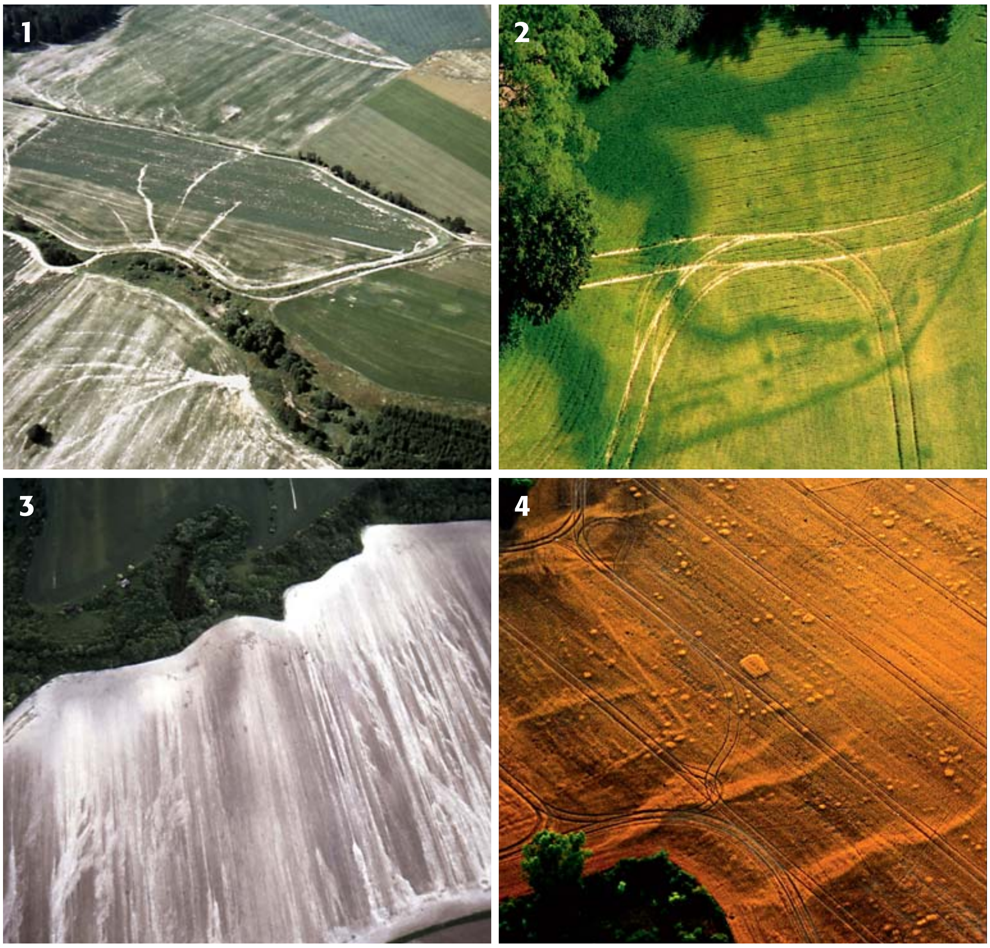

Fig. 4. *Examples of colluvial erosion:* ***1*** *– erosive rills;* ***2*** *– crop-marked double ditch at the top area of the Sazená hillfort (distr. Kladno);* ***3*** *– compact massive top (arable) layer slide (Central Bohemia);* ***4*** *– crop-marked settlement from the late phase of the Early Iron Age (Straškov, distr. Litoměřice; see chapter 6) and traces of colluvial erosion on this site. —* ***Obr. 4.*** *Příklady svahové eroze:* ***1*** *– erozní rýhy;* ***2*** *– linie dvou paralelních příkopů na vrcholové plošině hradiště Sazená (okr. Kladno);* ***3*** *– masivní plošná eroze ornice (střední Čechy);* ***4*** *– sídliště z konce starší doby železné (Straškov, okr. Litoměřice; viz kap. 6) a stopy svahové eroze na této lokalitě.*

processed as points (polygons) in the digital environment – today primarily using GIS. Although it must be borne in mind that for various reasons (apart from those that change annually, this is mainly the slope of the terrain, the intensity of ploughing and deforestation, because they affect erosion, the process standing behind the decrease of arable layer thickness and, as a consequence, behind the crop-marking over buried pits, ditches, sunken houses, etc.; *Fig. 4*) archaeological relics are visible on the surface by some of the indicators (most often vegetation) in the vast majority of cases only as certain parts of larger units, another fact is significant. While the total size of the area filled with components usually cannot be determined, vegetation marks provide the overall ground plan of a specific part of one settlement area (or several overlapping settlement areas; *Fig. 5*) and we can determine its qualitative and quantitative composition, i.e., the type representation of individual features, their mutual spatial relationship (which in the case of the regular placement of structures expresses their probable contemporaneity) and their affiliation to one and the same settlement area. A set of these components can be used for additional analyses. The results of aerial surveys conducted systematically for at least several years, primarily in the lowland settlement zone (which has always been the most densely populated landscape type – especially in large river basins) confirm the dense prehistoric settlement of many locations compared to the source base collected by long-standing practices, while also informing us about the type and number of features with which these locations were filled (see *Fig. 2*). In countries where aerial archaeology has long tradition the number of sites evidenced in national databases amounts to several tens of percent – for example, according to English Heritage (personal communication by C. Stoertz, Historic England) it is approximately 25%; according to *Hanson – Oltean* (*2002*, 109) 50% of all lowland sites in UK have been recorded from the air.

People long ago recognised the phenomenon of vegetation marks. They were first mentioned in 1541 in a work by the English antiquarian J. Leland (*Fagan 1959*), and as an indication of the presence beneath the surface of covered relics of an anthropogenic origin interpreted a century later by W. Camden (*Wilson 1996*, 42–43). In Central Europe, specifically in Bohemia, the observation of vegetation marks was first recorded in the middle of the 19th century, when K. V. Zap reported on this phenomenon in connection with the description of the battlefield near Kolín, the site of one of the bloodiest battles in the Seven Years' War fought a century earlier (1756–1763), and identified the places with vegetation marks with the graves of soldiers killed in this military clash (*Zap 1855*; for records of the occurrence of vegetation marks before the era of aviation, see also *Benson – Miles 1974*; *Schmidt 1893*, 244–247; *Píč 1903*, 9). Since the 1920s, the issue of vegetation marks as by far the most frequently used indicators of relics buried

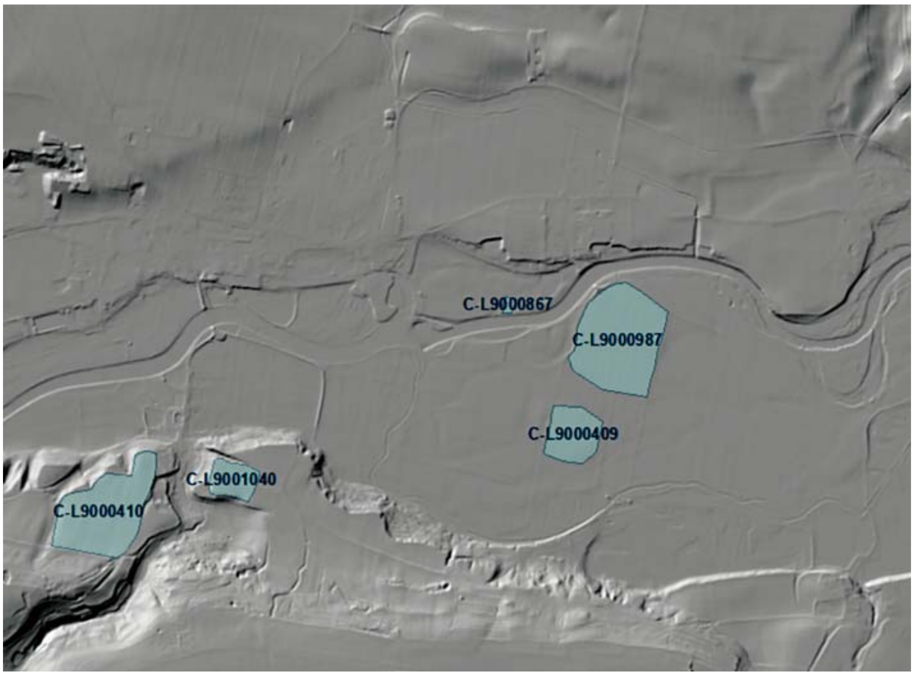

Fig. 5. *Areas (light blue-coloured polygons placed in the DTM of the Ohře/Eger River valley, NW Bohemia, and marked by evidence number) with recorded archaeological cropmarks termed 'localities' in the AMCR. These are clusters of prehistoric and ancient features whose mutual relationship (connectivity) is unknown. The space between individual clusters can hold other buried features which are invisible due to unfavourable conditions. Map scale 1 : 20,000. —* ***Obr. 5.*** *Areály (modře zbarvené polygony umístěné v digitálním modelu terénu v povodí dolní Ohře označené evidenčním číslem), v nichž byly evidovány porostové příznaky zahloubených objektů, v AMČR označované termínem „lokality". Jedná se o shluky pravěkých a mladších objektů, jejichž vzájemné vztahy (vazby) nejsou známy. V prostoru mezi jednotlivými shluky se mohou nacházet další pohřbené objekty, které však kvůli nepříznivým podmínkám nejsou porostovými příznaky zviditelněné. Měřítko mapy 1 : 20 000.*

underground in the European area has been the subject of permanent professional interest (*Crawford 1929*; *Riley 1944* and *1983*; *Jones – Evans 1975*; *Stanjek – Fassbinder 1995*; *Palmer 1996*; *Bewley 1996*; *Wilson 2000*; *Barber 2011*, 111–127). Several texts have been published especially in the last decade based on the experience of researchers with observing growth and colour changes during the vegetation cycle at their studied sites (e.g., *Rączkowski 2011*, 40–41), or which use statistics to attempt to create predictive models of the probable occurrence of cropmarks in connection with soil conditions and geomorphology (*Czajlik et al. 2021*). *Agapiou et al.* (*2013*) addressed the issue of the identifiability of vegetation marks (specifically in the Mediterranean) on a set of multi- and hyperspectral satellite data in connection with the spectral band and on the results of terrestrial spectroradiometer phenological cycle measurements (performed in 2001–2012). Attention is paid to the identifiability of archaeological sites from phenological information on satellite data (*Kirk et al. 2016*; *Agapiou et al. 2012*), data collection using artificial/machine intelligence or automatic classification (*Davis 2020*; *Stott – Kristiansen – Sindbæk 2019*; *Luo et al. 2019b*), and procedures related to the visibility of defunct immovable relics (*Verhoeven 2016*; *Agudo et al. 2018*; *Coakley 2019*; *Gojda 2017*). The results of the Czech project contributed to clarifying issues concerning the differences in the chemical composition of the topsoil and subsoil between features visible by the effect of vegetation marks and the surrounding (archaeologically sterile) environment, and in the height and chemical composition of barley growing above and away from sunken features of prehistoric origin. Data on soil and plant biomass from collected samples were evaluated using special chemical analysis procedures (factorial ANOVA and one-way ANOVA methods using the STATISTICA program). High soil pH and concentrations of phosphorus, calcium and potassium were found in sunken features and in their surrounding area in the topsoil layer, allowing us to conclude that chemical indications of prehistoric settlement activities can be determined by chemical analysis of not only subsoil layers (or the secondary fill of features), but also of the topsoil (*Hejcman – Součková – Gojda 2013*).

3. The first step. The processing of recorded archaeological sites revealed by cropmarks: from interpreted aerial photographs to vector polygons on digital maps

Since the start of the practical implementation of GIS in archaeology in the 1990s, the way in which vegetation indicators mapped the presence of subsurface objects has been influenced mainly by the British *National Mapping Program* (NMP, today *Historic England Aerial Investigation and Mapping* – https://historicengland.org.uk/research/results/reports/46-2019), probably the most globally ambitious cultural heritage mapping project – in this case of England – based on the analysis of aerial photographs and the archaeological interpretation of cropmarks captured on them (*Horne 2009*; for projects prior to the NMP, see *Stoertz 1997*; *Palmer 1984*). It became a source of inspiration for the long-term aerial survey programme that has been part of the scientific research agenda of the IAP since 1992, specifically its segment launched in 2014 focused on the cartographic processing of archaeologically interpreted aerial photographs of roughly 800 sites with features of prehistoric and historic age (*Fig. 6*) detected and documented during aerial survey campaigns (*Gojda – Čulíková 2015*). Utilising the potential of this now fully digitized archive fund available to the public on the Institute of Archaeology website (specifically in its Digital Archive of the Archaeological Map of the Czech Republic –

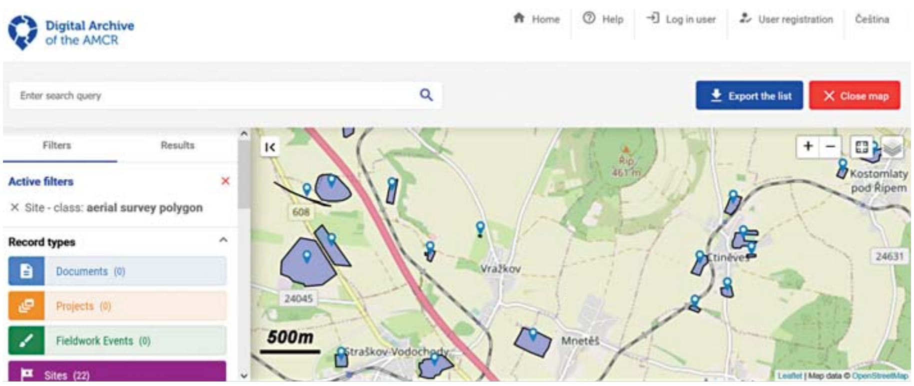

Fig. 6. AMCR: the distribution of 'localities' (blue coloured polygons) in the landscape around the Říp Hill, one of the Czech regions in which archaeological sites revealed annually via cropmarks are spread in a dense network. — ***Obr. 6.*** AMČR: rozmístění „lokalit" (modré polygony) v krajině pod Řípem, v jednom z českých regionů, kde jsou prostřednictvím porostových příznaků lokality každoročně zviditelňovány ve velkém počtu.

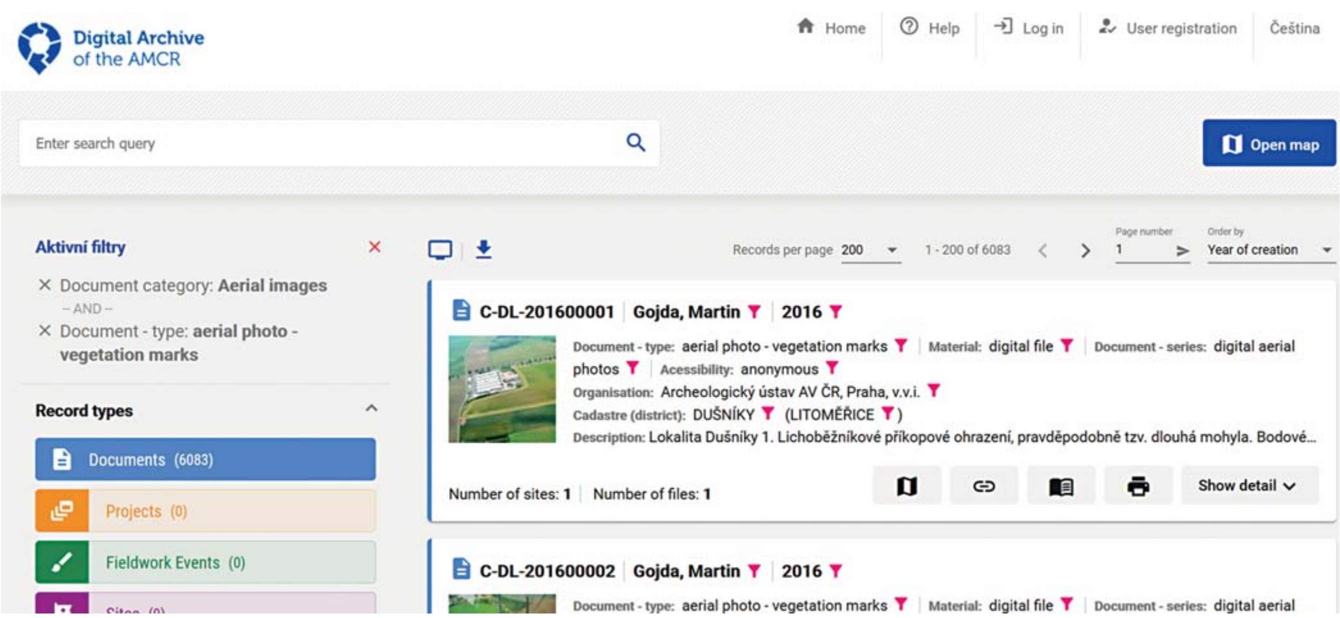

Fig. 7. *Digital archive of the AMCR – homepage of the document type 'aerial photo – vegetation marks', a section of the document category 'aerial images'.* — ***Obr. 7.*** *Digitální archiv AMČR – úvodní internetová stránka dokumentu typu „letfoto vegetačních příznaků", která je součástí kategorie dokumentu „letecká fotografie".*

https://digiarchiv.aiscr.cz/; *Fig. 7*) means transferring the interpreted oblique aerial images of buried archaeological sites capturing mostly through vegetation marks the manifestations of prehistoric and historic settlement activities into the form of their digitized plans placed in the form of a shapefile vector layer in the GIS environment (*Fig. 8*). The point is that photographs taken with a hand-held camera need to be rectified, i.e., the oblique image is converted into a vertical image in which the distances between the objects and their relative position – in the original photograph captured in distorted form – correspond to reality as accurately as possible and are displayed in a deducible scale. In this way, the information stored in the aerial photograph obtains the same quality as is required in the documentation of immovable archaeological features during field excavations: we know their exact size, shape, dimensions and mutual spatial relationships (*Malina 2020*; *Gojda et al. 2022a*).

A great advantage today is the possibility to work with orthophotomaps from the environment of map portals during rectification, especially for two reasons. On the one hand, it is possible to use the larger number of features captured on them, which can serve as reference points (these are not captured on topographic maps), while on the other, a large number of sites in the form of vegetation marks are captured and made visible on survey images available on online portals (*Fig. 9*). The optimal solution is to perform rectification in the GIS environment with the help of georeferenced aerial survey images and orthophotomaps (especially from the geoportal of the State Administration of Land Surveying and Cadastre, from the collections of the companies Geodis and TopGis on the www.mapy.cz server, or from the most globally widespread Google Earth / Google Maps portal). On their basis, the oblique images are rectified and their archaeological content can be digitized and vectorised in a separate layer. In this way, it is possible to combine the plans of all sites captured by aerial photography, which can then be viewed against topographic maps or aerial or satellite orthophotomaps available in GIS via map services (WMS). At the same time, this process creates records of individual features captured in the images, including their own metadata description. This data can be used not only as a basis for mapping, but also as primary data for research purposes.

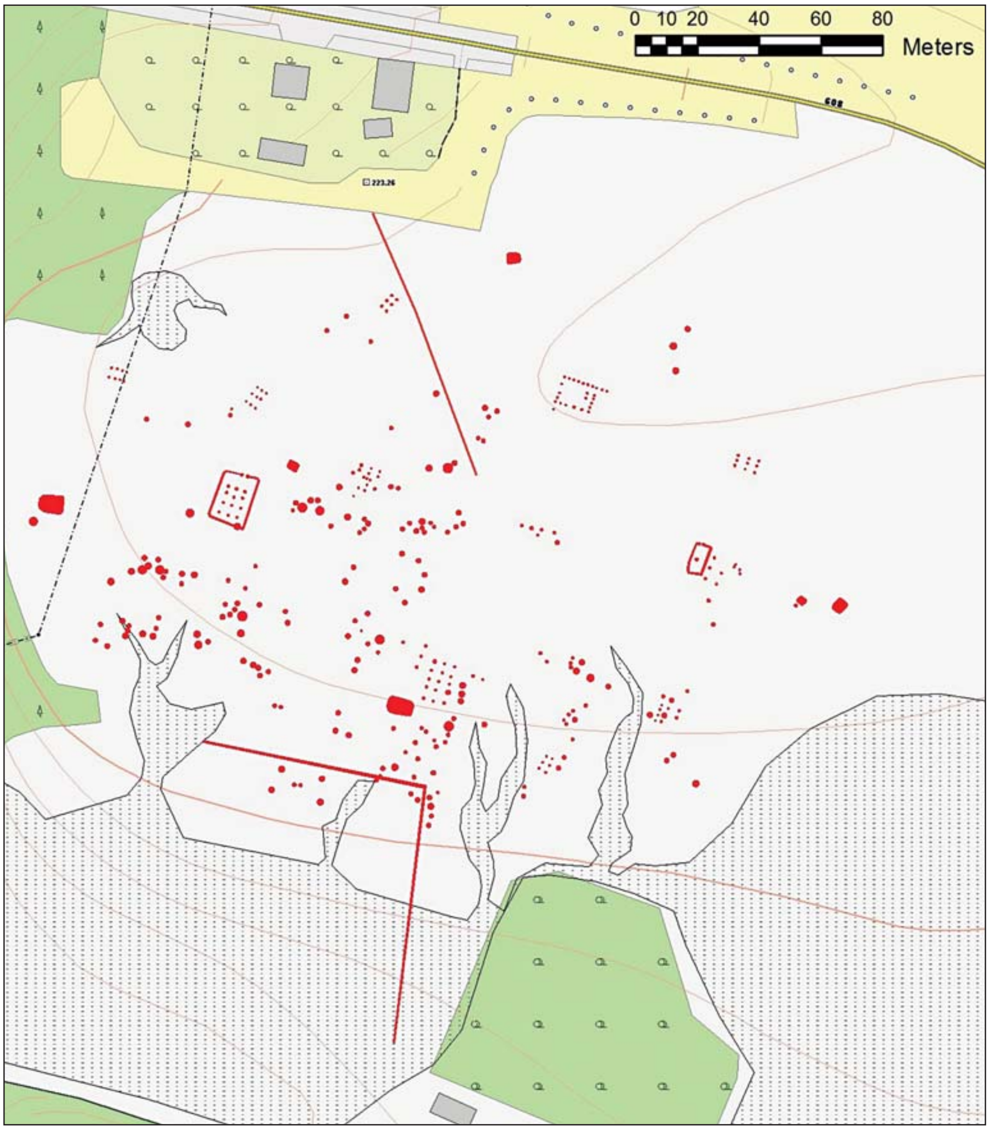

***Fig. 8.** Transformation of archaeological components as interpreted in aerial photos to a vector shapefile in ArcGIS. Vectorised plan of the Straškov site (distr. Litoměřice), one of the Bohemian 3D reconstructed crop-marked sites (see Chapter 6). — **Obr. 8.** Transformace archeologických komponent interpretovaných na leteckých fotografiích do vektorové vrstvy v programu ArcGIS. Vektorizovaný plán lokality Straškov, jedné z lokalit rekonstruovaných do podoby virtuálního 3D modelu (viz kap. 6).*

The final product of this process is a detailed 2D map of archaeological sites showing the layouts of all features now hidden underground, but which are visible today thanks to vegetation marks (e.g. *Fig. 8*). To date, 250 sites have been mapped in this way as part of the IAP's project, and in the near future it will be decided in which regime the layer of vector polygons of aerially identified sites will be made available to the professional and general public and subsequently incorporated into the Archaeological Map of the Czech Republic (AMCR) available at www.archeologickamapa.cz.

4. The second step. The aerial photogrammetry-based production of 3D images of sites with cropmarks

Compared to previous analogue outputs, the introduction of digital technologies in aerial archaeology has brought a whole new dimension, with the final data becoming three-dimensional, multifunctional and virtual. Technological advances have not only influenced the ways of acquiring and processing data, but have greatly expanded the possibilities of aspects of their research, especially the ability to simulate various aspects in a virtual environment and visualise them. The expansion of the traditional presentation framework to include virtual space has created the conditions for a change in the system and methods of presentation of archaeological contexts of vegetation marks.

Along with the transformation of features of archaeological interest (recorded on the basis of the interpretation of aerial photographs stored in the Digital Archive of the IAP, https://digiarchiv.aiscr.cz) into polygons of the vector layer on the digital archaeological map, 3D images of selected sites are acquired. These serve both for more detailed knowledge of the specific characteristics of vegetation marks of the documented site – especially the difference in the height of crops (which can be measured at higher resolutions) growing above buried archaeological features and away from them, and to obtain a more detailed visual image of the site and its topography (*Stal et al. 2013*; *Remondino 2011*; *Ioannidis et al. 2000*).

The method of Image Based Modelling techniques with Structure from Motion (SfM) was primarily chosen

Fig. 9. *Orthophotos of the Ctiněves site (distr. Litoměřice; see Chapter 6) from the years 2006 (**a**), 2014 (**b**), 2016 (**c**) and 2019 (**d**), as recorded on the internet map server www.mapy.cz. Cropmarks of more than 200 pits, two rectangular ditched enclosures and other structures are well recognisable in images taken in 2006 and 2016 in late spring. As vertical orthorectified and georeferenced images they have been applied as support for the GIS-based vectorisation process. —* ***Obr. 9.*** *Ortofotografie lokality Ctiněves (okr. Litoměřice; viz kap. 6) z roku 2006 (**a**), 2014 (**b**), 2016 (**c**) a 2019 (**d**) zpřístupněné na mapovém serveru www.mapy.cz. Porostové příznaky více než 200 jam, dvou čtyřúhelníkových příkopových ohrazení a několika dalších objektů jsou výrazně dobře patrné na snímcích z roku 2006 a 2016 na konci jara. Jakožto kolmé ortorektifikované a georeferencované snímky byly použity při vektorizaci této lokality v prostředí GIS.*

to convert the visual side of sites with vegetation marks into digital three-dimensional form, and data from laser aerial scanning in combination with aerial imaging were also used in part. In the past two decades, these digital technologies supporting the identification and documentation of archaeological sites have become essential tools for their study, protection and promotion (*Daly – Evans /eds./ 2005*). Although digital documentation technology is already an integral part of modern archaeological research, only recent rapid development primarily in the field of UAV (on the use of drones in archaeological survey, see e.g., *Risbøl – Gustavsen 2018*; *Themistocleous et al. 2015*) and the optimisation of software for SfM have provided the possibility for complex, fast and affordable processing of even large archaeological sites and larger landscape units (*Westoby et al. 2012*).

Both UAV imaging and manual SLR imaging were used to document sites with vegetation marks in central and northwest Bohemia (*Fig. 10*). The two methods were combined due to the area of the studied subject and so that the obtained data could be used for the planned 3D computer animation. In order to capture all or part of the site in greater detail, an image from a DJI Mavic PRO drone with a 4K camera with the possibility of taking 12 Mpix pictures was used, with several hundred vertical photographs usually taken from lower heights. Manual imaging from an aircraft was used to capture the overall landscape character needed for understanding the location of the site on a specific georelief map (terrain edge, spur, the distance from a watercourse, etc.) or in the case the area of the given site was greater. The aircraft usually flew around the site in a circle with the point of interest at its centre, and several dozen photographs were taken from the angle determined by the tilt of the aircraft. A Nikon D2 SLR with a resolution of 13 Mpix was used, and a GoPro HERO 5 with 12 Mpix resolution was also tested (the stabilisation mechanism of this camera perfectly eliminates shocks caused by flight conditions).

The acquired photographs were processed in Agisoft Photoscan Professional software, long a mainstay in archaeology, using the usual workflow for processing aerial images. During the processing of manual imaging from the aircraft, several reference points (Ground Control Points – GCPs) were inserted for georeferencing – more significant objects (e.g., high voltage transmission towers), for which it was possible to read spatial coordinates from some freely available websites. For photographs from the UAV, the direct import of spatial coordinates of individual images from the GPS drone was used, which provides sufficient topographic accuracy for the given purposes (*Carbonneau – Dietrich 2017*). This procedure was chosen mainly for practical time reasons (the limited time when vegetation marks can be observed), or some sites were not even physically visited (when imaging from an aircraft).

The resulting digital 3D model of the site was exported in one of the usual formats, including texture

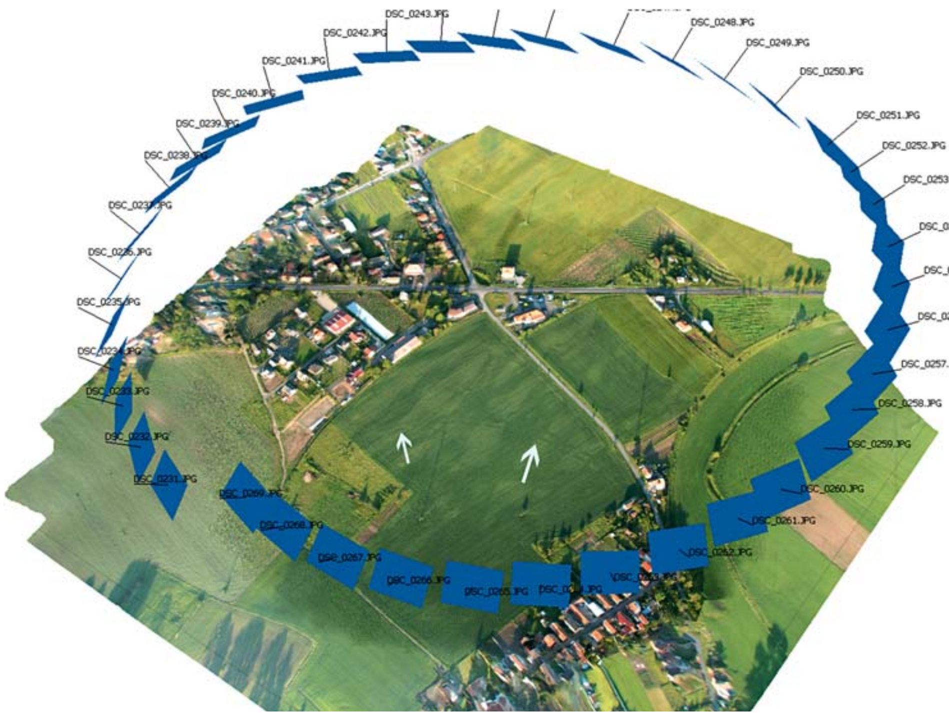

Fig. 10. *Placement of oblique photographs taken from drone over a double ditched-and-palisaded enclosure (Kly, distr. Mělník; see chapter 6) from an aircraft for the purpose of photogrammetric DTM production of the site and the following 3D virtual reconstruction. —* ***Obr. 10.*** *Umístění šikmých fotografií pořízených dronem nad příkopovým a palisádovým ohrazením (Kly, okr. Mělník; viz kap. 6) za účelem tvorby DTM fotogrammetrickým zpracováním velkého počtu leteckých snímků a následného vytvoření 3D virtuální rekonstrukce této lokality.*

(OBJ, FBX, 3DS), thus allowing its further editing in 3D modelling software (Blender, Sketchup). Alternatively, another workflow took place directly in Lumion rendering software, where additional data in the form of computer reconstruction models were added to the digital terrain model. It was also possible in the Lumion software environment to continue working with materials to highlight vegetation marks, while another significant advantage was the ability to simulate various lighting conditions. The rendering of static images or video also occurred here, supplemented based on the given situation by other effects such as phasing animations, the movement of model parts, changes to model variants, etc. The final video post-processing was performed in Corel VideoStudio, which in addition to the usual functions such as editing or timing video, allows you to add additional graphic elements, including text.

5. The final step. Towards 3D computer reconstruction models of heritage revealed by cropmarks

5.1. The creation of 3D computer reconstructions

Archaeological sources are by no means a simple reflection of the human past, as the information they provide about past cultures is highly distorted, both qualitatively and quantitatively (*Neustupný 1986*, 528). As a result of ‘extinction transformation’, archaeological sources have undergone increased entropy and an enormous loss of information; in order to overcome this transformation, modelling is an essential starting point (*Neustupný 1986*, 529–530) for attempts to resuscitate dead sources. By their very nature, archaeological sources are therefore always incomplete, which greatly complicates efforts to interpret them and, of course, to reconstruct and visualise. In connection with the creation of three-dimensional computer reconstructions of archaeological situations, it is necessary to consider ‘data uncertainty’ and the possibility of displaying this uncertainty in visualisations.

In archaeology, it is not possible to eliminate uncertainty in the data; it is always present to a certain extent, and in the case of reconstruction models, several hypotheses can usually be considered (*Eitelhorg 1995*; *Kantner 2000*, 47). The main factors of contextual and spatial uncertainty can thus be caused by the type of available data, their completeness, reliability and interpretation, while the main problems in visualisations are geometry, location, age, colour, texture, material, construction, context and landscape (*Brusaporci 2017*). In the reconstruction model, three areas are affected by uncertainty – shape, material and appearance (*Apollonio 2016*, 177). Therefore, the London Charter, the international convention on the design and presentation of 3D computer reconstruction models in archaeology, states that visualisation should provide precise information on the differences between real data and hypotheses and between different levels of their probability (*Denard 2012*, 60). Methods for visually designating uncertain data in computer reconstructions have been dealt with in previous projects, usually by marking this information using a colour scale, mixed transparency, a combination of colour scale and transparency, or by using different renderings of the model surface. The principle that reconstructive visualisations should have clear relationships between individual components according to their credibility thus requires a flexible rather than rigid absolutist approach. The London Charter does not provide a detailed list of necessary operations, but provides a structured set of suggestions determining specific measures that may be appropriate for an individual feature with respect to concrete objectives and circumstances.

Years ago, *Paul Reilly* (*1992*, 160) pointed out the need for a proper description of all data in order to facilitate their later analysis. The content of the model is generally based on metadata, which are descriptions of technical aspects, and paradata, which include a decision-making and interpretation framework, both of which are essential in obtaining a specific uncertainty scale (*Brusaporci 2017*, 67–68). The description of critical data, subjective decisions and ideas enable the range of possible interpretations to be evaluated in later analysis (*Bruschke – Wacker 2016*, 257). Only documentation maintained in this way provides sufficient explanation about the transparency of the reconstruction creation process and the credibility of the visualised model. Thus, skipping this process can substantially invalidate the scientific knowledge on which it was based and devalue the entire reconstruction model. The connection between the data used and the interpretation of its use is thus fundamental to the assessment of the reality contained in the models and, as such, clearly separates reconstruction from art (*Bruschke – Wacker 2016*, 257). The systematic classification of techniques for visualising uncertainty (*Pang – Wittenbrink – Lodha 1997*) involves adding pictograms, modifying geometry, attributes, animation, and sound, and proposes the use of various visual stimuli depending on whether the data is numeric, vector or categorical.

5.2. The process of creating and presenting 3D computer reconstructions in a project

The basis for the creation of a 3D computer reconstruction of sites revealed by vegetation marks was a model obtained using SfM, or a combination of aerial imaging and LiDAR, which contained full colour information about the surface, i.e., there were recognisable vegetation marks on it. The 3D computer model of the studied area intended for import into the graphic software environment was thus made in a photorealistic style with a high degree of detail. The use of photorealistic rendering in archaeological computer reconstructions has been the subject of a long discussion which usually concludes that they are unsuitable for academic environments (*Olivito – Taccola 2014*, 181; *Wittur 2013*, 48). The use of a photorealistic style theoretically means a high degree of certainty when the geometry and appearance of the feature is reconstructed on the actual measured data, which in our case is met and in combination with other graphic styles accepted by the professional community (*Bakker – Meulenberg – Rode 2003*, 161; *Olivito – Taccola 2014*, 182).

This type of output can thus be relatively easily and conveniently combined with other computer modelling, where real and interpreted data can be clearly distinguished. Thus, simple geometric or texturally distinguishable objects that indicate non-existent structures can be placed on a photogrammetric model based on reality. As such, there is immediately a clear difference between photorealistic parts with a high level of detail and thus high data certainty and between abstract modelled parts. We used this approach, for example, at the large settlements of Bříza and Straškov, where hypothetical reconstructions of settlement features such as sunken houses, granaries, hay barracks, fences, etc., were used for a photorealistic terrain model with a clearly visible spatial distribution of individual vegetation marks.

The creation of computer models of reconstructions of individual crop-marked features was based primarily on available information for a given period, when the appearance of the aboveground parts was based on interpretations of archaeological excavations of the identical time period and region. If they were available, earlier drawing reconstructions of similar features by various authors were taken into account, a comparison with data from experimental archaeology was performed and available historical analogies were used. In the majority of cases, the modelling took place directly into the orthophoto with visible vegetation marks, or into plans, where the vegetation marks were converted into vector form in the GIS environment and the reconstruction models were subsequently set in the digital terrain model. For 3D reconstructions, data achieved by the application of geophysical prospection can be helpful just in a limited way, because being based on contactless measurement they bring a kind of indirect information, from the methodological perspective similar to information extracted from crop-marked buried sites. On the other hand, of importance are geophysical data brought from sectors of archaeologically positive sites on which some parts of their areas have – for whatever reason – no capacity to produce cropmarks over buried features.

In order for the final visual outputs from the performed 3D computer reconstruction models to be more than just ‘pretty pictures’ (*Reilly 1991*) reducing 3D visualisations to mere works of art (*Barceló 2001*; *Sanders 2012*), video animations were chosen as the main outputs. This type of output allows the visualisation to be expanded by a great deal of additional information expressed in textual and graphic form, which can then tell the viewer the story of the form and significance of the site in an engaging way while preserving the appropriate scientific message.

A concept was typically chosen in which the form of a ‘fly through video’ is used in the introduction, i.e., with the camera moving over the area of interest from an aerial point of view so that both the observed vegetation marks and the location of the site in the landscape are clear. Due to the different annual visibility of vegetation marks, at this stage photos from other seasons were inserted into the flight at the same angle and height from where they were taken, allowing the viewer to see their different manifestations in a matter of seconds depending on the weather at the time and the crops that were being grown. At the same time, the area of interest is also graphically highlighted or the individual vegetation marks are graphically extracted, and it is thus clear to the viewer what will be the focus of further action. When the results of the archaeological survey of the site were available, plans from field research, geophysical prospecting, and in one case a 3D photogrammetric model of an identical feature captured in a rescue excavation in the same region were inserted into the digital model in the appropriate place. The animation of the computer reconstruction of the studied features was produced in a phased manner so that the very process of creating reconstruction models, the form of their placement in the field and their basic construction elements are evident, thus allowing the expert to directly assess the accuracy of the interpretation and execution of the 3D computer reconstruction; in turn, the lay viewer will be able to more easily understand their design and function. When it was necessary to understand the context, other teaching aids were used, including a cross-section of the feature, marking metric data or other data, such as in the Poplze video depicting the existence and position of the road that the fortification was to have controlled. Only sometimes in the final part of the video was a full realistically textured reconstruction of the site provided, including the surrounding landscape and human figures in order to provide the lay viewer with a better idea of the depicted realities. This type of visual expression has a significant emotional effect, and the viewer identifies with the image.

6. Virtual 3D reconstruction models of assorted crop-marked sites

As part of the project *Archaeology from the Sky* undertaken by the IAP in the years 2018–2022 and financially secured by a grant from the Ministry of Culture in the programme for the support of applied research and development of national and cultural identity (NAKI II; identification number: DG18P02OVV058), targeted imaging of selected archaeological sites made visible by vegetation marks was used for the first time in the Czech Republic with the aim of creating three-dimensional models of selected sites using the method of multi-image photogrammetry, which is subsequently employed for the creation of their 3D computer reconstructions. This chapter provides an overview of basic information about the ten sites processed using the above procedure. When compiling the list of sites to be included in the project, we primarily wanted to cover sites of different ages and functions so that their selection represented a qualitatively diverse group of identified and subsequently recorded and documented monuments whose relics are completely buried beneath the ground and are manifested only indirectly due to the different (time-varying) characteristics of agricultural crops growing above their ground plans and in the area away from them.

The video 3D virtual reconstructions of the sites listed in this chapter are available at https://youtube.com/playlist?list=PL7b9FwaRRVBNt4AN4L2sscLvro4fCC6lo.

Prehistoric rural settlements

Straškov (Litoměřice district; *Figs. 8, 11*)

The site, a part of which is visible by vegetation marks, has an area of c. 6.5 hectares and is situated on a terraced sandy ridge with a distinctive edge on the north and west side, which descends to the valley of the Čepel Stream and its tributary, the Věšínský Stream. This is a site where detected features were associated with a residential function (sunken dwellings; aboveground post-built structures – though their function could also be non-residential), with storage and the disposal of waste (granaries, waste pits). These are the above-mentioned aboveground post-built structures documented by the ground plans of five structures which, thanks to the results of a number of archaeological rescue excavations carried out in the Czech Republic in recent years (*Gojda et al. 2022b*) date this site to the late phase of the Early Iron Age (the Hallstatt period, the Bylany culture in Bohemia). The site is evidently part of a relatively large prehistoric residential area situated in the western part of the landscape below Říp (see *Fig. 6*). In addition to several burial features – grave pits located in the middle of a circular ditch enclosure dated by excavations to the Middle/Late Bronze Age, and besides a circular medium-sized ditch enclosure (c. 25 metres in diameter) with entrance interruptions facing the cardinal directions, which can most likely be identified as a Late Neolithic rondel (these features are located c. 200–400 metres north of the Straškov settlement), in the context of the Straškov site it is important to mention the sites around Straškov dated to the Early Iron Age. Additional sites were recorded with evidence of prehistoric settlement (E and NE part of the cadastre of the village of Račiněves) to the north of the village. One was a Bylany culture burial ground, which was repeatedly probed during the 20th century (1911 – J. L. Píč, 1913 – A. Stocký, K. Buchtela, 1933 – J. Böhm and an American expedition). The most recent investigation in 1998–2006 was conducted by D. Koutecký (Institute of Archaeological Heritage, Most), who subsequently published a general overview of the results of all previous field activities at this site (*Koutecký 2008*). During the aerial survey in May 1998, it was even possible to identify two of the mounds (position 4) that were captured in the probes in 1911, 1933 and 2006: circular enclosures with a diameter of about 15 metres and labelled on the map in Koutecký's cited work (*Koutecký 2008*, obr. 3, 5, 27) as graves 3 and 5 (this area is now destroyed by advancing sand mining), which were visible through vegetation marks (ditches/gutters visible in this way were not recorded at any of the mentioned excavations). Given the dating of settlement features in the area of the Straškov site to the Early Iron Age (Bylany culture), we have in this case unique evidence of the Bylany settlement area, i.e., about its burial and residential component (the nearest Bylany burial ground is recorded in Budyně nad Ohří, i.e., at a distance of approximately 10 km; *Koutecký 2008*, 389). The two sites are about 2 km apart and are separated by a valley at the confluence of the Čepel and the Račiněves Stream, so the visibility from one site to the other is very good. While the residential/storage (or waste) area is situated at its southern edge, on a flat terrace with a distinct northern and western edge, the burial ground is located on a slight flat slope of the local valley.

Thanks to repeated aerial and archaeological survey campaigns, the Straškov site is one of the best documented areas not only in the Říp region, but in the entire territory of the Czech lowland landscapes where aerial and archaeological survey is conducted (*Gojda – Trefný et al. 2011*, 33–36).

Fig. 11. *Straškov (distr. Litoměřice):* ***a*** *– crop-marked Early Iron Age aboveground houses (****2, 3****), an undated sunken house (****1****), and irregularly dispersed settlement pits (****4****);* ***b, c*** *– 3D virtual reconstruction of the site (author: J. Unger). —* ***Obr. 11.*** *Straškov (okr. Litoměřice):* ***a*** *– vegetačními příznaky dokonale zviditelněné půdorysy nadzemních domů ze starší doby železné (****2, 3****), (polo)zemnice blíže neznámého pravěkého stáří (****1****) a nepravidelně rozptýlených sídlištních jam (****4****);* ***b, c*** *– 3D virtuální rekonstrukce lokality (autor: J. Unger).*

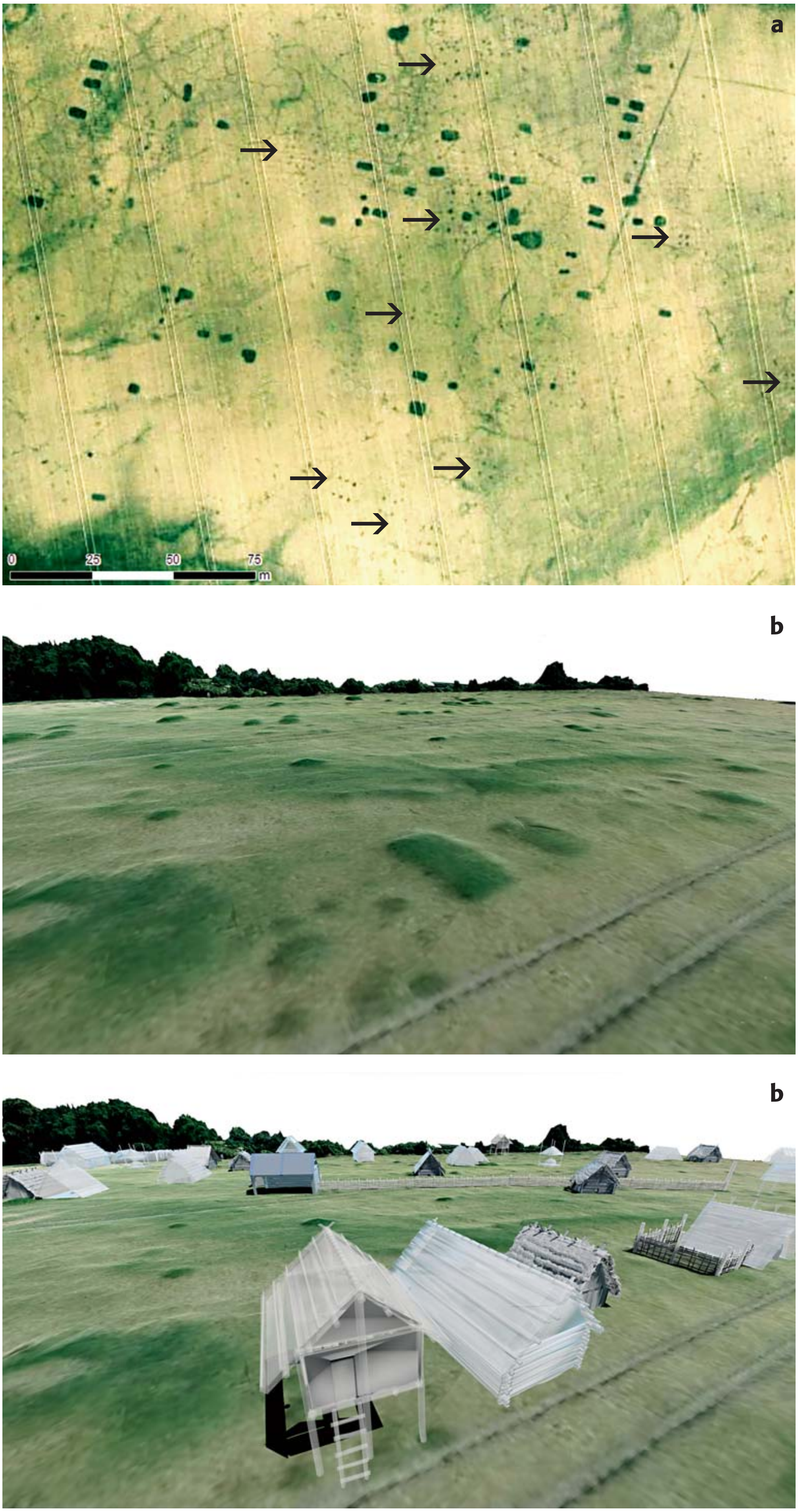

Fig. 12. *Račiněves (distr. Litoměřice): **a** – large area covered by cropmarks indicating the presence of many buried prehistoric features, including plans of formerly aboveground post-constructed buildings dated to the Early Iron Age (marked by black arrows; source: www.mapy.cz); **b** – 3D virtual reconstruction of the site (author: J. Unger). — **Obr. 12.** Račiněves (okr. Litoměřice): **a** – rozsáhlá plocha sídliště s vegetačními příznaky řady pravěkých pohřbených objektů včetně nadzemních sloupových domů ze starší doby železné (jejich půdorysy jsou vyznačeny černými šipkami; zdroj: www.mapy.cz); **b** – 3D virtuální rekonstrukce lokality (autor: J. Unger).*

Račiněves (Litoměřice district; *Figs. 3, 12*)

The site is located on the edge of a flat hill, on a gentle slope, 600–800 m from the stream (Račiněves Stream). The site is characterised by:

(a) its large size (the surface of the visible part of the area is c. 14 hectares). The situation on the north side is difficult to read due to the dark colour of the field caused by the accumulation of eroded topsoil from the hill on which the site is located. Despite this, spot features are also visible on this surface. Due to the large size of this poorly legible terrain, it cannot be ruled out that the total area is in fact larger and includes (many) more features than those captured by aerial photographs;

(b) the considerable predominance of dwellings over pits; the sunken houses have an average size of 3.5–5 × 2–3 m and are oriented in the east-west direction with certain deviations; such a large accumulation of sunken dwellings at a single site is very unique in the context of all parts of Bohemia studied by the method of aerial archaeology.

(c) the presence of sunken spot features, the occurrence of which has been recorded at many other areas and the interpretation of which is ambiguous (small sunken houses?, large grave pits?). They are similar in shape to dwellings; their longer side is slightly shorter than in the case of dwellings, but their width is usually smaller (average size: 2.5–3 × 1.5–2 m);

(d) in addition to dwellings and pits, several individual enclosures (2–4 curvilinear, 1–2 rectilinear; some ground plans are poorly legible) and spot features arranged in a certain system (individual and parallel rows of postholes, of which the latter represent the floor plans of aboveground buildings, of the same type known from Straškov).

Apart from aerial survey, only a surface collection has been carried out at the site (in its south-eastern part) to date. However, the assemblage of pottery fragments found here is quite fragmentary and does not allow a more precise determination of their age (only generally to later prehistory), with the exception of significant specimens dating to the Early Middle Ages.

Prehistoric rural settlement and burial ground

Ctiněves (Litoměřice district; *Figs. 9, 13*)

The site is located on a sandy terrace with steep slopes significantly higher than the surroundings on the south and west side, below which springs one of the branches of the Vražkov Stream. The area above the developed part of the town of Ctiněves, on the SW edge of which is the local Church of St. Matthew with its adjacent cemetery, is one of the best-known archaeological sites in the Říp region, which has repeatedly received the attention of chroniclers, local history workers, amateur and professional archaeologists, but also illegal treasure hunters and local residents. The reason for the increased interest in this site was mainly the fact that the tomb of the Forefather of Bohemia was traditionally (from the Early Modern period, i.e., the 16th century) thought to be here in the field east of the church (*Sklenář 2008*, 49–51). The largest number of finds from earlier times comes from the Late Bronze Age (Knovíz culture – collections by M. Lüssner from 1867, J. Hrala from 1970 and M. Najman from 1986). This dating was also confirmed by an extensive campaign of analytical collections that took place within a project of the Department of Archaeology of the University of West Bohemia in Plzeň (*Trefný – Švejcar 2011*). After all, the origin of most of the spot features in the Ctiněves area could already be estimated on the basis of their large number, which is typical for the Late Bronze Age settlements of the Knovíz culture and which were confirmed by the excavation of a similarly vast site discovered by aerial survey in Lišany in the Louny region (*Smrž – Majer 1995*). As the images show, it is a large accumulation of about two hundred spot features – pits, a small circular enclosure (diameter 4–5 m) with a spot feature inside and, finally, a feature that consists of three parts – an outer irregular square (24 × 24 × 26 × 26 m) and an inner slightly trapezoidal ditch enclosure (c. 13 × 8 × 15 × 10 m); roughly in the middle of the outer enclosure is a large spot feature that can be interpreted as a separate burial chamber.

All the aforementioned reports as well as the results of the latest field events suggest that this significant, strategically situated position on the flat Lower Ohře plateau was used repeatedly in the past for various settlement activities. Based on current knowledge, including that gained from the interpretation of data from aerial and geophysical surveys conducted in 2006, it can be stated that this is probably the core of a settlement area used in prehistoric times for residential and burial purposes. With the exception of the immediate vicinity and the interior of the large enclosure, virtually the entire SW tip of the local terrace was inhabited in the Late Bronze Age. According to the previously cited data, traces of settlements from the Late Eneolithic and Early Middle Ages were also documented in the studied Ctiněves area. Unfortunately, the question of the exact age and purpose (probably burial) of both the enclosure and the central pit remains unclear even after three seasons of excavations (*Krištuf – Švejcar – Trefný 2011*).

Hillfort – prehistoric and early medieval enclosed (fortified) settlement

Přerovská hůra (Nymburk district; *Fig. 14*)

A significant terrain block with an extensive peak plateau forms an important landmark 50 metres above the local Elbe lowlands. Due to long-term ploughing of this site, only slight remains are preserved from the original fortifications. Specifically, these are two parallel ditches (clearly visible in aerial photographs due to both vegetation and soil marks) and two banks visible in a digital terrain model (DTM) derived from LiDAR data at the eastern end of Hůra. At the western end of the plateau, the lines of two ditches are clearly visible in aerial photographs (they were also detected by magnetometric measurements – *Křivánek 1996*), and on the DTM also the lines of one bank, which is practically undetectable when viewed from the ground. Some places at this site have been subjected to archaeological excavation sev-

Fig. 13. Ctiněves (distr. Litoměřice): ***a*** – aerial photo of the SW part of the site; ***b*** – photogrammetry-based 3D model of the site (author: J. Unger). — ***Obr. 13.*** Ctiněves (okr. Litoměřice): ***a*** – šikmý letecký snímek JZ části lokality; ***b*** – 3D model porostových příznaků lokality pořízený metodou vícesnímkové fotogrammetrie (autor: J. Unger).

eral times since the end of the 19th century, and the finds obtained from here date the local settlement to several periods of late prehistory. The fortifications of the Hůra peak can most likely be dated to the Late Hallstatt period and the Early Middle Ages (*Čtverák et al. 2003*).

Prehistoric ritual/ceremonial (?) area enclosed by a double ditch

Kly (Mělník district; *Fig. 15*)

In 1997, east of the town of Kly, a large area was identified by aerial survey for the first time in the Czech Republic, which in the context of Central European agricultural prehistory (or the Proto- or Early Eneolithic in the Bohemian chronology) we classify in the category of specific large areas enclosed by a single or multiple (typically parallel/concentric) ditches, occasionally also palisade trenches, which surround either the entire space of the area up to tens of hectares, or part of it, if the artificially unenclosed part of the perimeter of the area is protected by a naturally suitable local georelief. The Kly area is situated in the Mělník region, in the heart of the territory most intensively studied by aerial survey. The structure itself, located immediately to the east of the village of Kly, has all the characteristic elements that are mostly represented in these large enclosures only selectively – a multiple ditch, palisade gutter, and entrance interruption (*Gojda et al. 2002*). Its location, dimensions and morphology are similar to features known from neighbouring countries. This is a large enclosure composed of a pair of ditches (the outer and middle line) and a palisade trench (inner line). We know this scheme both from Danube / Central European Late Neolithic circular features – rondels, and from later German and Scandinavian Erdwerke (earthworks). The outer ditch is visibly disrupted in six places,

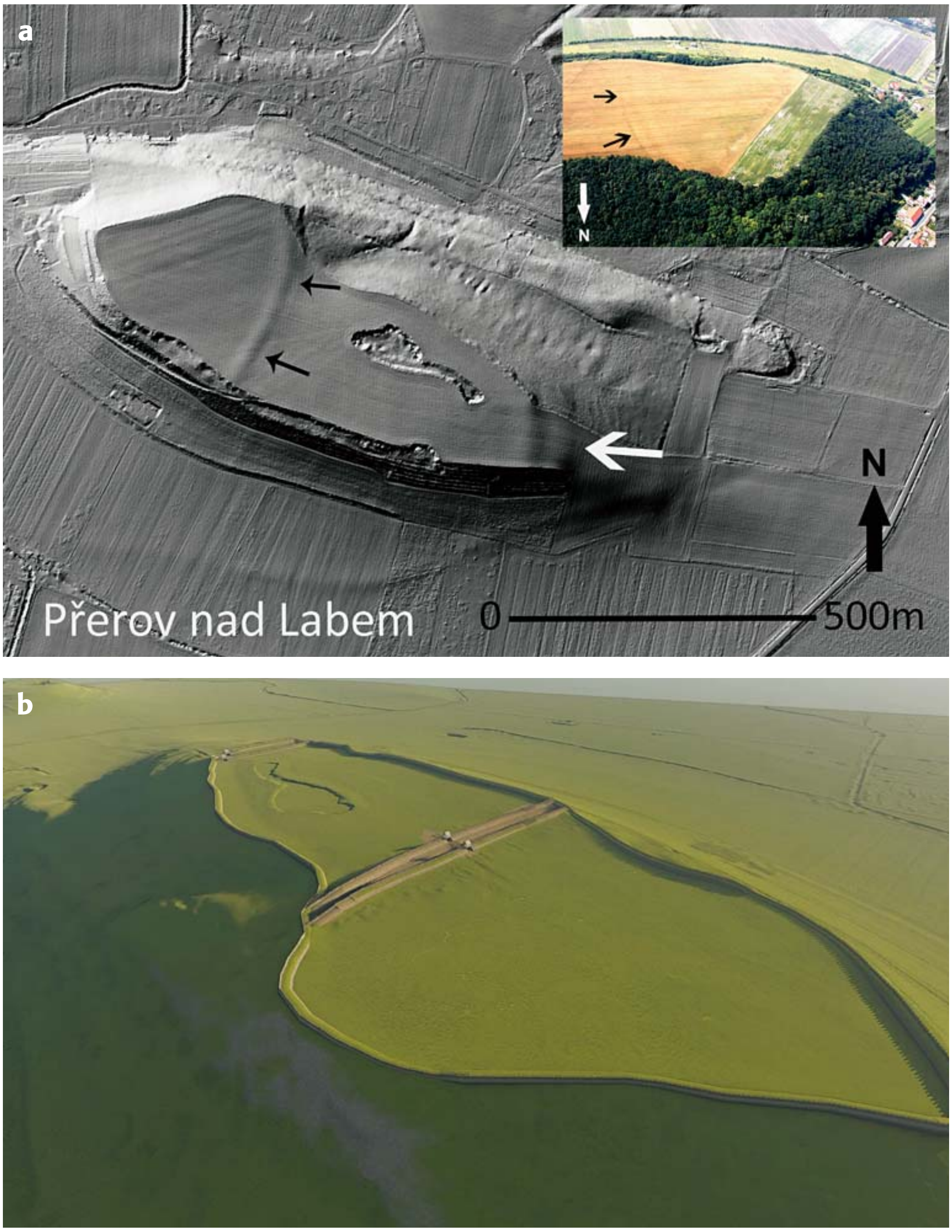

Fig. 14. Přerovská hůra (distr. Nymburk): ***a*** – DTM of the site produced from LiDAR data with visible low rampart relics and a double ditch displayed via cropmarks (top right); ***b*** – 3D virtual reconstruction of the site (author: J. Unger). — ***Obr. 14.*** Přerovská hůra (okr. Nymburk): ***a*** – DTM lokality pořízený z leteckých lidarových dat s patrnými liniemi nízkých valů a dvojitým příkopem zviditelněným porostovými příznaky (vpravo nahoře); ***b*** – 3D virtuální rekonstrukce lokality (autor: J. Unger).

the inner ditch in ten places. These openings coincide on the inner and outer ditch in four (at most five) places, otherwise they do not match up. The vegetation marks of the filled ditches in the images from the beginning of July 2010 are the clearest. On the publicly available map portal at www.mapy.cz, they appear on orthophotos from 2006 and 2015. In the last third of the 1990s, repeated geophysical measurements were taken in the Kly area; an excavation was conducted in the autumn of 1999 (*Foster 2004*) and in March 2000 analytical surface collections were carried out on the entire area (*Kuna 2004*). A reconstruction of the previous form of this area is also of great importance, as it indicated that at the time to which the ditch system is dated, the site was a promontory position (part of a Middle Pleistocene Riss terrace) about ten metres above the original Elbe riverbed, i.e., a site that must have attracted the settlement interest of local communities for strategic and/or symbolic reasons in the otherwise flat terrain of the broad alluvial Elbe Valley (*Dreslerová* in *Gojda et al. 2002*). Another excavation was conducted in 2015 (*Krištuf et al. 2019*).

Due to the mentioned similarities with previously registered and archaeologically investigated features in surrounding countries and especially due to the find of an entire vessel (a 'tulip' cup) in its primary deposition (the vessel was placed *in situ* upside down on the bottom of the inner ditch), the Kly area is dated to the Proto-Eneolithic, to the period of the Michelsberg culture (c. 4000 BC; *Zápotocký* in *Gojda et al. 2002*; *Bertemes 1991*). The double-trench and palisade system used in Kly is known, for example, from Heilbronn-Klingenberg (Baden-Württemberg; *Planck et al. 1994*) and from Urmitz (Rhineland-Palatinate; *Boelicke 1976*). In particular, the latter (the largest of its kind in Europe) is in many respects close to our enclosure: the outer

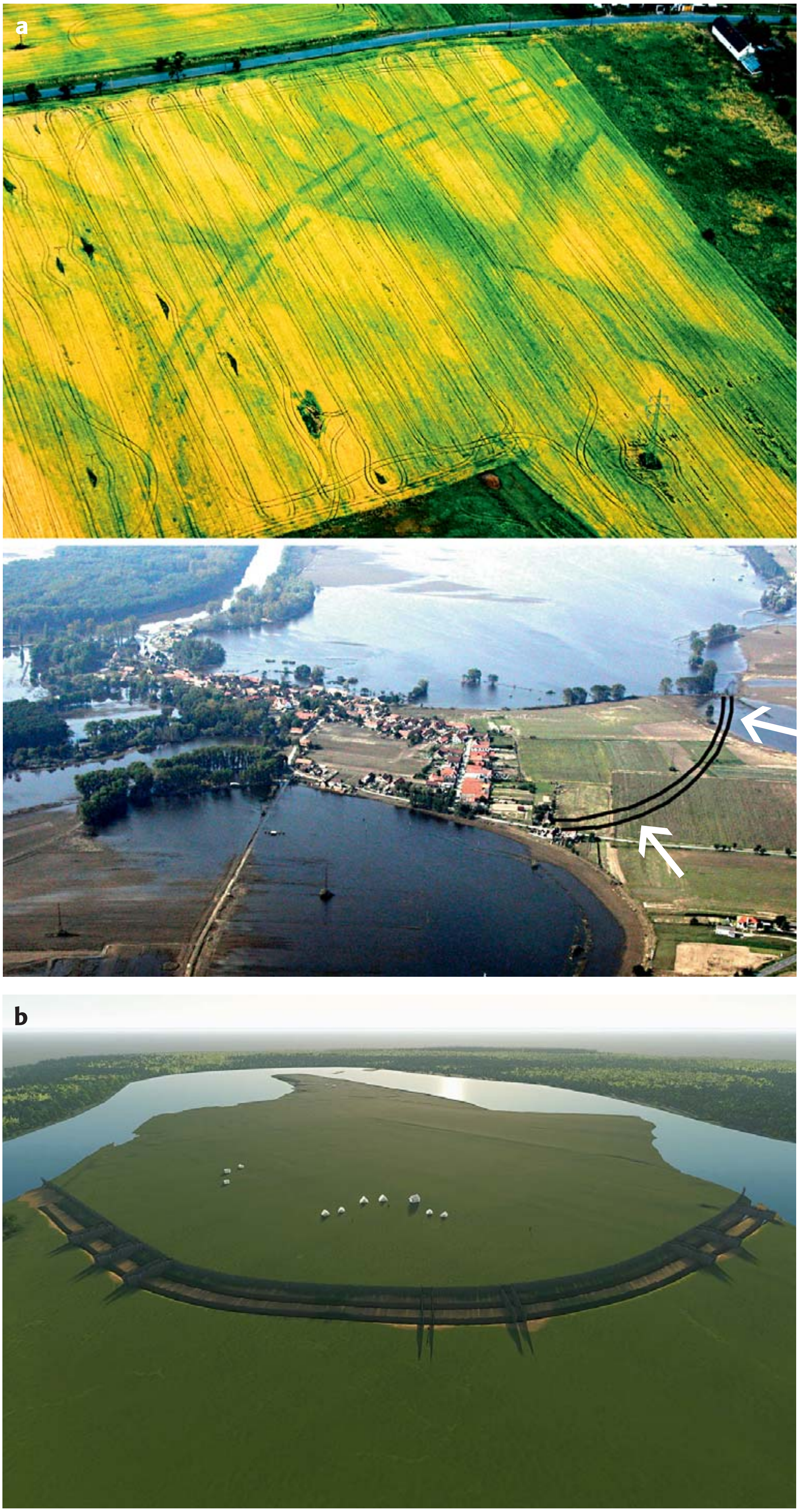

Fig. 15. *Kly (distr. Mělník):* ***a*** *– aerial images of the site (top photo – cropmarks of the double ditch-and-palisade trench displayed on barley; bottom photo – the site during the summer flood in 2002);* ***b*** *– 3D virtual reconstruction of the site (author: J. Unger). —* ***Obr. 15.*** *Kly (okr. Mělník):* ***a*** *– letecké snímky lokality (nahoře – vegetační příznaky dvou příkopů a paralelního žlabu palisády zviditelněné na ječmeni; dole – snímek pořízený během letní povodně roku 2002);* ***b*** *– 3D virtuální rekonstrukce lokality (autor: J. Unger).*

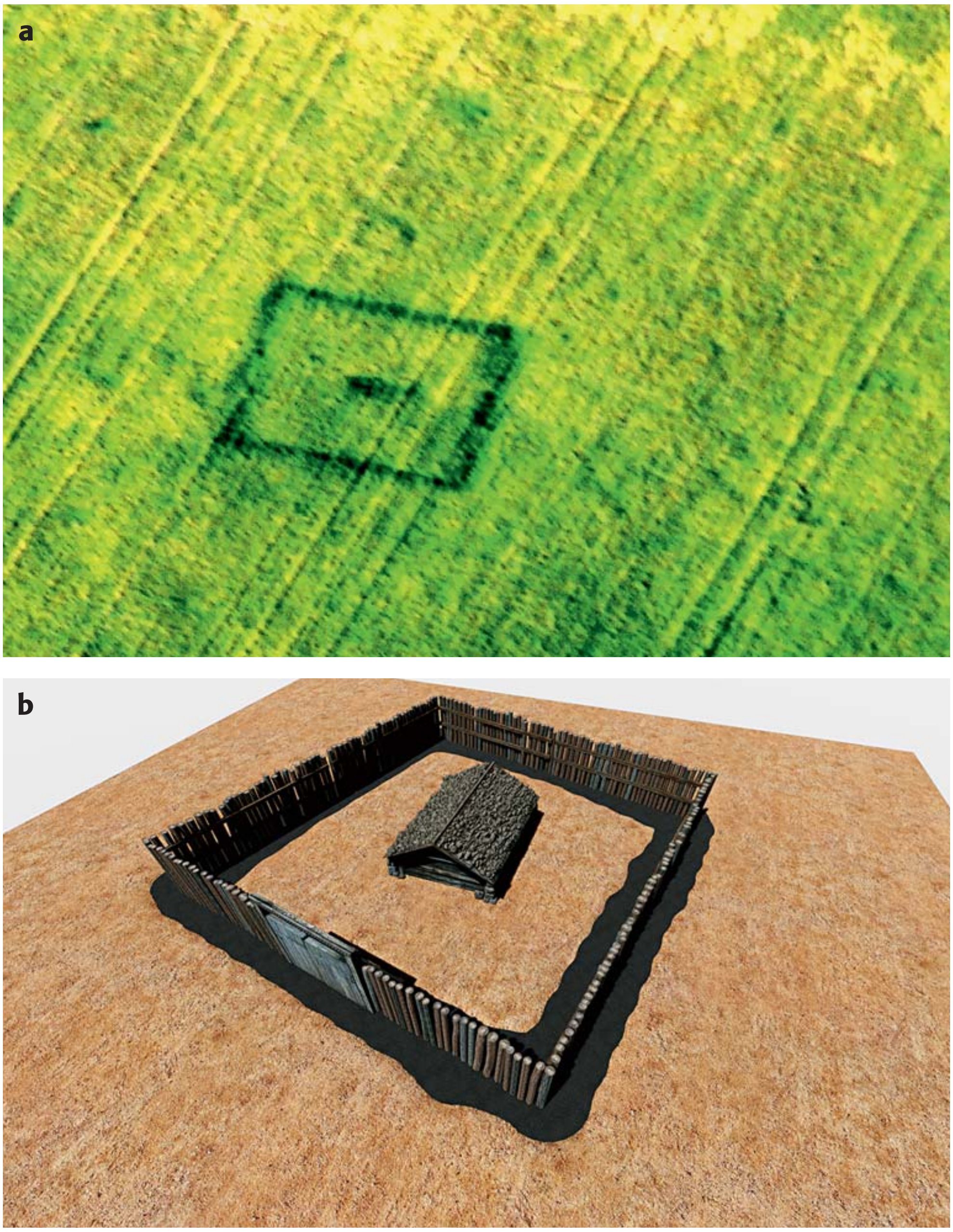

Fig. 16. Černouček (distr. Litoměřice): ***a*** – the crop-marked grave pit enclosed by a rectangular ditch on aerial photo; ***b*** – 3D virtual reconstruction of the site (author: J. Unger). — ***Obr. 16.*** Černouček (okr. Litoměřice): ***a*** – šikmý letecký snímek pohřební komory a čtvercového příkopového ohrazení; ***b*** – 3D virtuální rekonstrukce lokality (autor: J. Unger).

and inner ditches are interrupted by entrances at irregular intervals; at both sites, the outer ditch has fewer entry interruptions than the inner ditch; of the three lines of entry, the palisade trench had the fewest. 'Bastions' – auxiliary structures in the middle of the twelve entrance spaces of the inner moat of the Urmitz enclosure, may not have been missing at some entrances to the Kly structure, as indicated by the existence of a square feature in front of the entrance to one of the northern interruptions in the outer moat (the last one captured by aerial imaging, though not by the geophysicist). However, we also find all of these features that connect the Kly enclosure with the Michelsberg enclosure in the environment of neighbouring groups belonging – together with Michelsberg – to the Funnel Beaker culture (KNP), with the area of the northern KNP group being best documented in this area thanks to long-term excavations (*Andersen 1988*; *Madsen 1988*).

Prehistoric (barrow?) burial ground

Černouček (Litoměřice district; *Fig. 16*)

The burial ground near Černouček, consisting of one circular and one square ditch enclosure, was the very first archaeological site discovered in Bohemia by aerial survey in 1991 (*Gojda 1997*). The area has long been photographed from an airplane and a drone, surveyed by the GPR station and measured using a magnetometer. In 1997, the square enclosure was selected as an example of a monument of its particular kind and an excavation was conducted with the aim of gaining an understanding of the construction and chronological classification of this type of feature, one that had been previously unknown in Bohemia (*Brnič – Sankot 2004*). In the middle of the square ditch (14-metre sides), a burial chamber was uncovered with few finds from the original inventory (a pottery vessel and several iron artefacts: knife, rivets, bracelet, scalptorium, openwork belt clasp, ring), which together with the results of radiocarbon dating make it possible to classify the feature chronologically to the turn of the Hallstatt and La Tène periods (turn of Ha D3 and LT A), in absolute terms to the first half of the 5th century BC. Based on foreign analogies, the burial surrounded by a square ditch can be considered proof that the buried individual was a member of the nascent local social elite. With regard to the obtained data, the feature enclosed by a square uninterrupted ditch in Černouček appears as a delimitation of space (burial area) for the deposition of a central individual burial of a member of the social elite whose tomb was covered with a kind of wooden and stone structure, probably symbolising a posthumous dwelling. The excavation did not make it possible to determine whether the space inside the square enclosure was covered by a mound (from soil excavated from the perimeter ditch). However, given some foreign analogies, this is at least probable. As for the circular ditch enclosure located near the square feature and which, unlike the feature, was interrupted by a single entrance, even though its burial function is almost certain, it is not possible to determine without an excavation whether it comes from the same period as the square enclosure.

Early medieval rural moated site (farmstead/curtis/curia?)

Ledčice (Mělník district; *Fig. 17*)

The site discovered during aerial survey in 2000 is situated on a lower terrain wave (partially eroded due to long-term ploughing) in the otherwise flat surrounding land at a distance of c. 600 m from a nameless nondescript watercourse. It ranks among the most archaeologically intensively investigated areas in the Říp region (repeated aerial survey and photo documentation, surface collections, geophysical measurements, excavation).

Probes dug here in 2004 and 2007 documented the age of the feature, which dates back to the very end of the Early Middle Ages (turn of the 13th century / first half of the 13th century).

The overall ground plan of the feature consists of a few individual components (A, or A1–A2, B, C), which appear on a lighter background as dark lines and spots. They are highlighted by white arrows in places with poorer legibility. As can be seen in the *Fig. 17*, the area is composed of several parts. The main component consists of two areas delimited by a (peripheral) line, which due to its width can be almost unambiguously interpreted as a ditch, which was documented by magnetometric measurements and probes. In terms of stratigraphic relationships, both areas obviously respect one another, but it is not possible to determine from the aerial photographs whether they were created simultaneously and functioned together at one time horizon or throughout their existence, or whether one of these enclosures was added to the older one at a later date. If this was the case, the area with rounded corners can clearly be designated as the older of the two enclosed areas, since due to the occurrence of large spot features in its central part, it gives the impression of the central feature of the entire area. If, on the other hand, the nearly square A2 enclosure forming the southern section of two-part area A (the image shows the area from the west) were older, the photographs would have to show the continuation of the line of the ditch (filled in a later phase) in its northern part.

Another part of the area is the space situated east of the two-part ditch enclosure (component B). The photo shows a thin curvilinear line (highlighted by arrows) demarcating this space. Compared to the perimeter line of the main component of the investigated area, it is significantly thinner and it can be safely interpreted as a foundation trench for a palisade or fence. It is clear from the images that this line also functioned with a high degree of probability as an integral part of the entire area, because it is found in the NE corner of the two-part enclosure (of the main component of the area, i.e., A) and does not cross it. This component also includes spot features, which can be interpreted as pits and sunken dwellings based on their size and shape.

The last part of the area is a short straight line, which is an extension of the ditch on the east side of the square enclosure (component C). However, it is not located directly on it, but after a short break of 2–3 metres. Like the line of the foundation trench (component B), it ends at the north edge of the adjacent road (today the local road connecting Ledčice with the village Sazená), which already appears on the First Military Mapping and is still one of the few functional roads situated in the vicinity of Ledčice today. Considering the fact that the Quaternary geological conditions (subsoil type) and the current topsoil thickness are practically the same on both sides of this road, it is conspicuous that none of the lines of components B and C continue past this road in any aerial photograph taken so far. This allows us to assume the considerable age of this road or that the road already existed here at the time of the construction of the investigated feature and its position was determined so that its southern edge was adjacent to this road. Unanswered, of course, is whether the enclosure of component B remained open towards the road or whether it was also separated from it in some way.

In the context of current knowledge about the form of settlement/economic units of the landed nobility, the Ledčice area represents a unique situation that captures both the shape and size of the (two-part) farmstead and the enclosure of the adjacent area. The fenced area near Ledčice is, in the narrower sense, an estate (curtis). However, the absence of metal finds, especially military or equestrian and horse gear, the absence of 'luxury' finds, together with the poverty and uniformity of the pottery assemblage, puts the potential residential function of the area in a problematic light. Within considerations of an economic function, it is not possible to unambiguously interpret the dominant component; we can consider the raising of cattle, and other uses cannot be ruled out (pub, wine press, etc., or their combination; *Gojda et al. 2010*).

Fig. 17. *Ledčice (distr. Mělník):* ***a*** *– oblique aerial image of the site with arrows marking ditch-and-palisade trench;* ***b*** *– 3D virtual reconstruction of the site (author: J. Unger). —* ***Obr. 17.*** *Ledčice (okr. Mělník):* ***a*** *– šikmý letecký snímek lokality s vyznačeným průběhem ohrazujících příkopů a palisádového žlabu;* ***b*** *– 3D virtuální rekonstrukce lokality (autor: J. Unger).*

18th–19th century field fortifications

Poplze (Litoměřice district; *Fig. 18*)

Aerial survey aimed at identifying the remains of field fortifications from the summer of 1813, built hastily in the Ohře River basin after the formation of the Sixth Anti-Napoleonic Coalition (Russia, Prussia, England, Sweden, Austria) as a result of the threat of invasion by Napoleon's army from Saxony to Bohemia, as well as searches of written sources related to these events, led to the discovery of about two dozen features of the defensive line. Today, relics of the vast majority of them are completely buried under the surface of the terrain and can be detected under suitable conditions thanks to vegetation marks (*Gojda 2020b*; *Smrž – Hluštík 2007*).

The presented *hornwork* military feature near the village of Poplze was the very first field fortification identified in the territory of Bohemia. However, the oldest aerial photographs show only a part of the ditch enclosure, which was originally interpreted as a possible part of the local settlement from the Late Bronze Age, or a multicultural hilltop settlement located in the neighbouring 'Viničky' position (*Gojda 1997*); only later was the feature captured in its entire floor plan, allowing for its correct interpretation (*Smrž et al. 1999*, 335). The hornwork near Poplze – a field fortification covering a large area – is one of the features of this type of field fortification discovered in the eastern section of the studied line from 1813 (dimensions: 155 × 65–90 m; ditch width: 3.5–4 m). It is situated on the north-facing slope of the distinctive Ohře right-bank terrace, rising

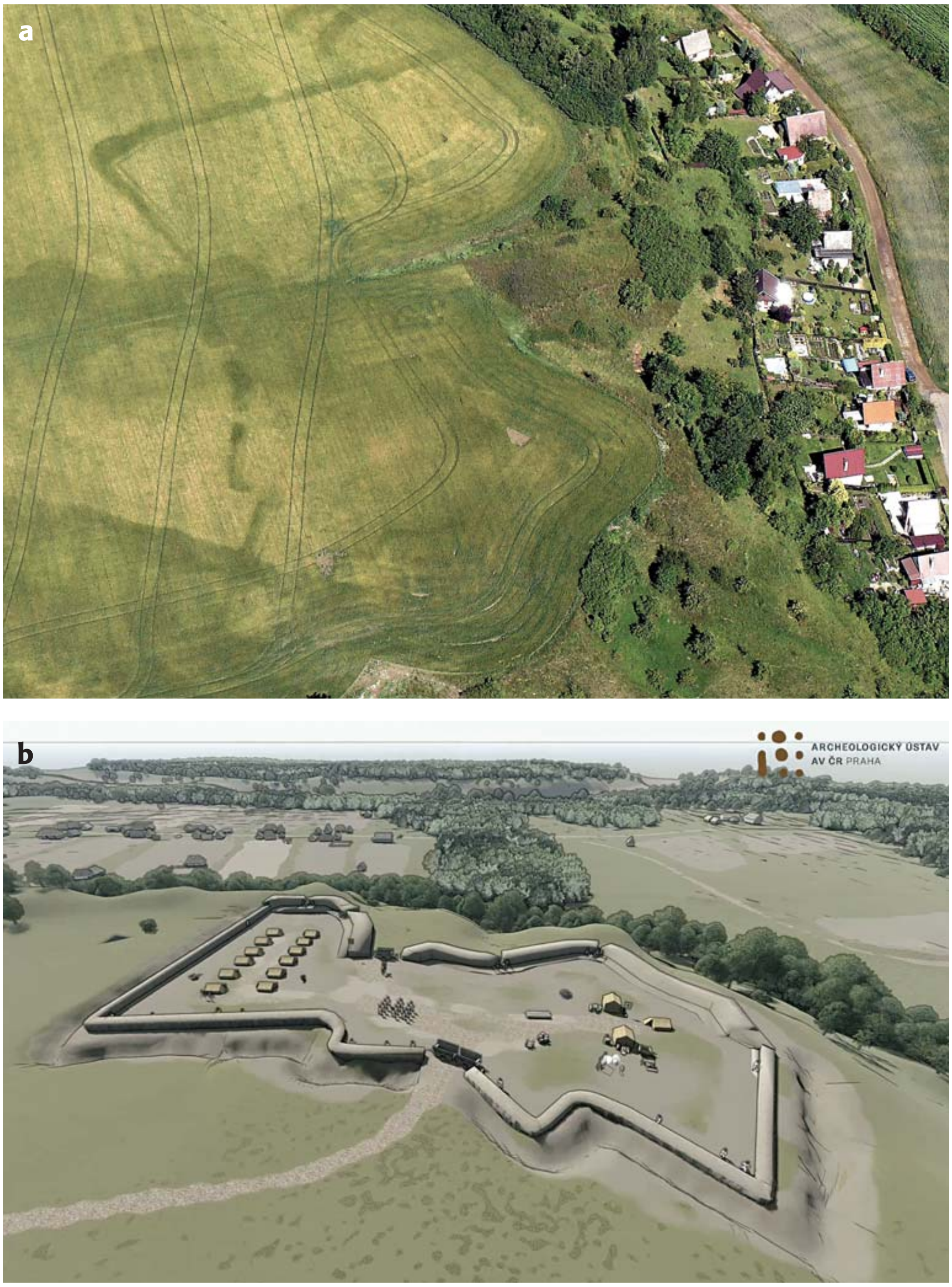

Fig. 18. *Poplze (distr. Litoměřice):* ***a*** *– oblique aerial image of the site;* ***b*** *– 3D virtual reconstruction of the site (author: J. Unger). —* ***Obr. 18.*** *Poplze (okr. Litoměřice):* ***a*** *– šikmý letecký snímek lokality;* ***b*** *– 3D virtuální rekonstrukce lokality (autor: J. Unger).*

above the river surface for about 10 km between Stradonice and Kostelec nad Ohří. The terrace towers 30 metres over the Ohře valley at the site of the fortification (the 'Salominka' location). As no ditch remains are preserved (due to colluvial erosion) on the northern side of the feature, it is not possible to determine whether the fortification was open on this side or enclosed by a ditch and a presumed earth mound, as was the case on the other three sides. It can be assumed that cannons intended for the protection of the southern bridgehead of Libochovice, located on the right bank of the Ohře River opposite Poplze, were placed in it. A detailed aerial image from June 2011 (see *Fig. 1*) demonstrates an interesting attribute, namely that the palisade was led outside at the southwest corner of the ditch, where it continued to run parallel to the ditch in front of its outer edge. From the *Fig. 18a* it is clear that its northern ditch line is interrupted by entrances in a total of three places.

Hořín (Mělník district; *Fig. 19*)

The group of four massive artillery batteries near Hořín at the confluence of the two most important Czech rivers, the Labe (Elbe) and the Vltava, above which rises an important historical town (and before its establishment an important central Bohemian administrative castle of the Přemyslid rulers of Bohemia), Mělník, is one of two sites of the type of *fort line of advanced massive artillery fortifications* identified by air reconnaissance to date. They represent a defence system characterised by a concentration of several massive artillery and infantry redoubts (referred to in these cases as

Fig. 19. *Hořín (distr. Mělník):* ***a*** *– oblique image of one of the four artillery batteries displayed via cropmarks;* ***b*** *– 3D virtual reconstruction of the site (author: M. Sýkora). —* ***Obr. 19.*** *Hořín (okr. Mělník):* ***a*** *– šikmý snímek porostových příznaků jedné ze čtyř dělostřeleckých baterií;* ***b*** *– 3D virtuální rekonstrukce lokality (autor: M. Sýkora).*

'forts'), which are either of the same floor plan type and are not interconnected by ditches, ramparts and parallel roads, or each was constructed on a different floor plan and their interconnection by a ditch line created a compact defence base. They were built either in front of bastion fortresses or near important landscape components (e.g., at the confluence of larger rivers) with strategic links to important roads, cities, etc.

The floor plans of the individual components of the fort line near Hořín, which are an example of the first of the types of these areas described above, have been gradually detected over the course of twenty years since the end of the last century. In total, this is a set of four large forts of a specific shape, the floor plan of which consisted of ditches 5–7 metres wide supplemented in at least one documented case by a palisade running parallel to its inner edge. Most likely, this defensive group was built as the easternmost part of the anti-Napoleonic defensive line from the summer of 1813 (*Honl 1933*). A survey of the entire area, which is farmed annually with recurring ploughing, is currently being prepared using the metal detector method. This could contribute to the definitive confirmation (or, conversely, to the challenging) of the assumption of its origin in the period of the final phase of the First French Empire. Anyway, also a possibility that the fort line near Hořín was constructed a half century later as a result of the tension between Prussia and Austria in the 1860s (which was terminated by the war in 1866) cannot be excluded.

Třeboutice (Litoměřice district; *Fig. 20*)

A complex of massive advanced artillery batteries, typologically distinct from the Hořín area, was built almost half a century later (shortly after the middle of the 19th century) on the distinctive right-bank terrace of the Elbe between Litoměřice, Trnovany and Třeboutice. Its primary purpose was to protect the massive Terezín

Fig. 20. *Třeboutice (distr. Litoměřice):* ***a*** *– original plan of the fortification line;* ***b*** *– oblique image of the site displayed via cropmarks;* ***c*** *– vertical photo of the site taken in the mid-1950s;* ***d*** *– oblique photo of the site taken in a late afternoon in winter – the buried parts of the line are visible via shadowmarks;* ***e*** *– 3D virtual reconstruction of the site (author: M. Sýkora). —* ***Obr. 20.*** *Třeboutice (distr. Litoměřice):* ***a*** *– původní plán fortové linie;* ***b*** *– šikmý snímek lokality s objekty zviditelněnými vegetačními příznaky;* ***c*** *– kolmá fotografie lokality pořízená v polovině 50. let minulého století;* ***d*** *– šikmý letecký snímek lokality pořízený v pozdních odpoledních hodinách v zimním období – pohřbené části liniového opevnění jsou zviditelněné prostřednictvím stínových příznaků;* ***e*** *– 3D virtuální rekonstrukce lokality (autor: M. Sýkora).*

bastion fortress built at the end of the 18th century from the impending invasion of Prussian troops into the territory of the Habsburg Empire. The individual forts of the main line, marked on the original plan as Werk I – Werk V (see *Fig. 20a*), were formed by ditches over 10 m wide, the embankments of which, built of excavated soil, reached a height of 2–3 m. The buildings were designed for installing artillery batteries. The whole system was closed at its eastern end by a fortress on Křemín Hill and was supplemented by smaller redoubts and redans situated in the floodplain of the Elbe riverbed on both of its banks. In contrast to the defensive arrangement of the batteries near Hořín, each of the Třeboutice fortified structures had a unique layout and the batteries were also interconnected by the line of an earth rampart, a moat and a road. Since the second half of the 1990s, this area has been continuously studied and photo-documented, and its components have been photographed from the ground several times.

Fortresses 1–6 (see *Fig. 20c*) are still captured as structures preserved in the terrain on military topographic maps (coordinate system S-42) from 1977 (though it is difficult to say what state of preservation they were actually in) and this condition is also captured in the aerial survey image from the mid-1950s (*Fig. 20c*). Today, structure 4 has been completely removed and the space it occupied has become part of the surrounding field. Until the end of the last decade, there was a belief that its remains were perfectly levelled and, under the influence of permanently applied agrotechnical procedures (ploughing, harrowing), could be captured in plan only through vegetation marks, photographically documented during aerial survey – for the first time in 1997. This assumption also seemed to be confirmed by ground photographs taken at the site: the surface of the field on which fort 4 is located bears the barely visible bumps that document the existence of the defunct structure. Only the testimony of two other sources from the field of remote sensing proved that the described objects are in fact still preserved in very low relief and even after two to three decades of ploughing could not completely level them with the surrounding terrain. This fact was first determined during a reconnaissance flight in late December 2009, when, thanks to the position of the sun, which at that time was just above the horizon, it was possible to take oblique photographs of the investigated fortifications, which have great testimonial value. The extremely low source of light was able to depict the exact floor plan of the defunct fort and other seemingly completely aligned parts of the fortifications, even with visually unrecognisable terrain irregularities (*Fig. 20d*). A particular uncertainty as to whether these were soil rather than shadow indications set in when, as part of a research project of the University of West Bohemia in Plzeň, LiDAR images of the entire system of advanced fortifications were obtained (*Gojda – John et al. 2013*).

The information contained in the data obtained by several remote sensing methods (aerial perpendicular/surveying photographs, oblique images taken by a hand-held camera from a low-flying aircraft, digital relief model obtained by remote laser scanning, topographic map) helped in the case of the Terezín advanced fortification system to assess the condition of this monument at a time when its integrity was essentially intact, i.e., about one century after the construction of the entire complex (1950s) and thus capture the original appearance of its individual parts. This applies, for example, to a line formation connecting individual forts, which can be characterised in the photograph in question as an earth embankment (rampart), practically defunct today, to which a road adjoins on both sides. Combined with the testimony of mainly oblique photographs (specifically those that capture vegetation marks) and the LiDAR image, the original situation can be reconstructed so that the line adjacent to the rampart on its northern side is a filled ditch, and the line on the opposite side was probably a road sunk below the level of the local terrain. This line is visibly thinner in the photographs, which illustrates the ground plan of the sunken parts of the fortification system with perfectly drawn contours, and its width corresponds to the line of the parallel, south-facing and now defunct road, which was still functional a half century ago.

The reconstructed virtual model of the Třeboutice defensive line is focused on individual forts (constructed according to their original plans; *Fig. 20e*) while the adjacent linear (ditch/road/rampart) system was simplified: its possible appearance was not reconstructed and just one line – a ditch – was included to the resulted virtual model.

7. Evaluating the credibility of computer animation

While visualisation is a more powerful means of expression compared to text, its explanatory value may be diminished in the absence of a proper description of the model building process. If the visualisation does not clearly communicate the process of its creation, how the research questions were asked, how carefully the available information was studied and interpreted, or how exacting or creative the reconstruction is, will be of little consequence. Besides the creation of the visualisation itself, documentation of how decisions are made about the various components of the model plays an important role, and the importance of documenting this process is essential to ensure a level of transparency, which is even mentioned in the London Charter (*Brusaporci 2017*).

For the selected video animations, we thus attempted to express their credibility by means of a table (*Tab. 1*) including both metadata and paradata of the displayed scenes. A rating system permitting a selection from three options was chosen for each of these, and multiple variants were not entered mainly to limit subjective decision-making as much as possible. Based on the chosen option, each of the descriptors is assigned a value of 100, 50 or 0, the data are added up and averaged to obtain a final percentage expression of the trustworthiness of the given computer scene.

The *Table 1* contains three basic parts: the first part (1–4) is devoted to the evaluation of the available data used in the construction of the digital scene of the site with vegetation marks, the second part (5–8) quantifies

Tab. 1. *Sites achieve the highest credibility first of all thanks to a complex remote sensing documentation (UAV, aircraft, more seasons) in connection with data from fieldwork and non-invasive survey. When the 3D computer reconstruction is properly executed it is possible to achieve hypothetical credibility of computer animation of a particular site up to 80%.*

	Straškov	Račiněves	Přerovská hůra	Kly	Černouček	Ledčice
1. Drone survey	100	100	0	0	100	100
2. Use of scanning from multiple seasons inputs	100	100	100	100	0	100
3. Use of LiDAR	0	0	100	100	0	0
4. Use of GIS plans	100	100	0	0	0	100
5. Use of excavation results	100	0	0	100	100	100
6. Use of results from non-destructive investigations	0	0	0	100	100	100
7. Identification of vegetation marks	100	100	50	100	100	100
8. Known analogies	100	50	100	50	100	50
9. 3D reconstruction graphically distinguished	100	100	0	0	0	100
10. 3D reconstruction phased	100	100	0	0	100	50
Credibility	**80%**	**65%**	**35%**	**55%**	**60%**	**80%**

the data necessary for the creation of computer reconstructions of archaeological features, and the third part (9–10) also takes into account whether the video satisfies international conventions for the display of digital reconstructions.

The first part considers whether a drone was used at the site, because this type of documentation allows its most detailed digital documentation usable both for the recognition of vegetation marks and for the creation of a 3D computer model of the relevant terrain. Due to the varying appearance of vegetation marks depending on the climatic conditions in the different seasons, whether the site was surveyed more than once or whether other sources such as satellite maps or aerial photography were used was evaluated. Moreover, due to the high spatial accuracy of these methods, the use of airborne laser scanning data and plans created in GIS were also included.

The second part of the table describes the possible pitfalls in the creation of computer reconstructions of features derived from the manifestations of vegetation marks, where the availability of results from field archaeological excavations or non-destructive surveys was an essential evaluation criterion, as this type of data significantly increases the probability of a correct assessment of the type and function of the given feature, which are otherwise estimated only on the basis of vegetation marks. For the same reason, the actual legibility of the vegetation marks is critical for the reconstruction of the archaeological contexts of interest, as is the question of whether analogies from similar archaeological contexts can be used as a basis for the reconstruction. For the credibility of the computer reconstruction with the viewer, it is also necessary to evaluate whether these reconstructions are distinguished from the surrounding real environment and thus communicate their distinct hypothetical nature, and also whether the construction of the computer models is animated so that the viewer can assess the process of creating the reconstruction.

As part of the visualisation uncertainty, we decided to try a wide range of different approaches to help the viewer interpret the credibility level of the displayed data based on methods that are applicable to three-dimensional computer models (*Griethe – Schumann 2006*); the following main forms were chosen: **free graphic variables** – they affect hue, texture, lighting, sharpness, transparency, and colour sequences can be used; **side by side** – compares two or more visualisations side by side; **animation** – allows dynamic representation and identification of changes; **integration of other types of data** – adding other objects such as pictograms, graphs, tables or text.

8. Discussion

Compared to verbal or textual communication, visual communication is a much more effective form, as it works faster, in parallel and in many dimensions (*Hrbek 1968*, 551). The choice of a graphic method of expression can thus accelerate the interpretation process, making it an easier, clearer and more concise form of communication (*Tondl 1996*, 176). And precisely because visualisations make it possible to significantly speed up the entire learning process, they are of great importance for use in teaching, science and its popularisation. This acceleration of the cognitive process is very desirable especially today, as the enormous influx of information limits the human ability to meaningfully classify and organise this quantity (*Nevěřilová 2004*, 4).

In contrast to traditional text forms, the shortening of the interpretation time making it possible, using appropriate visualisation, to quickly obtain an overall image of the given issue is of great service to science. Data visualisation in science is a means of learning and understanding hitherto unknown facts, which differs from typical presentation graphics, which display already known information and only facilitate communication. The visualisation of scientific data, on the other hand, is a tool that facilitates their synthesis, analysis and interpretation, and the method of research (*Sochor et al. 1997*).

In the field of information technology, visualisation is a method used to transform symbols into a geometric dimension, allowing you to perform further simulations and calculations. Visualisation is thus a form that allows you to see the invisible and offer new, unexpected perspectives in scientific processes (*McCormick et al. 1987*). Moreover, if we operate with features that are too complex, incomprehensible, or exist only in our minds, it is extremely desirable to create their visual models that serve to better understand their construction, organisation, or transformation. Modelling thus creates analogies to realities that do not have an actual visual form, which mainly concerns multidimensional non-existent structures or objects that change over time (*Nevěřilová 2004*).

The presented outputs are focused not only on the professional community, where the concept of video animation was directed towards the presentation of hard data and the construction of expert visualisation, but also to the general public, where emphasis was then placed on generating natural interest in the topic and the easy understanding of displayed information. The concept was also based on the fact that the outputs will be presented primarily on digital media and the internet, where the visualisation has only a few seconds to grab the viewer's attention. Therefore, the short form of a video lasting at most a few minutes, with fast scene changes and the use of motion in animation was chosen.

9. Conclusion

The processing of analysed and interpreted aerial photographs taken during active aerial survey from low altitudes into orthorectified and georeferenced maps (large areas with traces of past settlement activities made visible primarily by indirect – vegetation – indicators) and detailed plans of individual sites (i.e., accumulations of buried anthropogenic features of prehistoric and historical origin in a small area) can undoubtedly be considered the most important step in the process of their evaluation, both in terms of care for archaeological heritage and with regard to their further use in research. It is precisely this processing that multiplies the potential of discoveries made through aerial survey and archaeological interpretation of aerial/satellite photographs. The aerial images in the archive of the IAP will continue to be processed in this manner and in the transformed manifestation of maps and plans will become integral parts of the AMCR (www.archeologickamapa.cz) – the platform of the central Archaeological Information System of the Czech Republic (http://www.aiscr.cz). As hitherto produced (video animated) virtual reconstruction models of archaeological sites detected via cropmarks indicate their production based on the potential of computer 3D reconstructions in research and the popularization of its achievements extensively widen possibilities of image based archaeological interpretation of sites, features and monuments in terms of their original appearance. For this reason, the production of 3D reconstruction models of crop-marked heritage should be firmly included to the set of methodological instruments of current archaeology.

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English by David Gaul (text) and Martin Gojda (captions)

Souhrn

1. Úvod (*obr. 1*)

V průběhu posledních třiceti let probíhá v Čechách péčí Archeologického ústavu AV ČR v Praze (ARÚ) program, jehož cílem je shromažďování informací o archeologickém potenciálu vybraných oblastí (především nížin a povodí velkých řek v tzv. starém sídelním území) pomocí dálkového, konkrétně leteckého průzkumu za podpory dalších nedestruktivních metod. Od roku 2014 je prováděna analýza a interpretace leteckých fotografií pořízených v průběhu aktivního vizuálního letecko-archeologického průzkumu. Následně jsou v prostředí GIS mapovány (vektorizovány) rektifikované a georeferencované složky archeologické náplně identifikovaných lokalit, datovaných od mladšího/zemědělského pravěku do počátku 21. století.

Je to právě transformace interpretovaných fotografií archeologického nemovitého dědictví do map/plánů, již považujeme za jeden z nejdůležitějších kroků v procesu jejich zhodnocení, a to jak pro potřeby péče a ochrany památek, tak s ohledem na jejich využití ve vědeckém výzkumu.

Od roku 2018 jsme začali s pořizováním leteckých fotografií vybraných příznakových lokalit z bezpilotních letounů (dronů, UAV). Početné série snímků pořizované ve vrcholné fázi vegetačního cyklu zemědělských plodin nad každou z vybraných lokalit následně slouží k vytvoření digitálního modelu povrchu (DMP) prostřednictvím principu vícesnímkové fotogrammetrie, který umožňuje vytvořit videoklipy virtuálních letů pravěkými vesnicemi, hradišti, pohřebišti, vojenskými objekty a dalšími komponentami archeologické krajiny zviditelněnými porostovými příznaky. Poté DMP slouží jako základ tvorby 3D rekonstrukčních modelů lokalit, z nichž velká většina nebyla zkoumána odkryvem. Půdorysy vytvářené porostovými příznaky, které je často vykreslují ve velkém detailu, slouží jako základní prostředek k rekonstrukci pravděpodobné podoby modelovaných objektů.

Spatřujeme dvojí potenciál 3D rekonstrukčních modelů vytvářených z „neviditelných“ komponent archeologického dědictví – jako podporu větší systematické pozornosti archeologů analýze, zpracování a interpretaci dat dálkového průzkumu Země a jako metodu schopnou významně zvýšit zájem širší veřejnosti o minulost.

2. Vegetační příznaky jako projev krajinné paměti (*obr. 2–5*)

Význam tzv. vegetačních příznaků v archeologickém výzkumu je uznáván již od počátků letecké archeologie, jejíž dopad na evidenci nemovité složky archeologického dědictví a na tvorbu archeologických map byl v minulosti (*Maxwell /ed./ 1983*) vnímán stejně zásadně jako dnes (*Verhoeven – Cowley – Traviglia /eds./ 2021*; *Gojda 2020a*; *Tapete /ed./ 2019*; *Luo et al. 2019a*; *Opitz – Herrmann 2018*; *Forte – Campana /eds./ 2016*). Informace o archeologických nemovitých památkách shromažďované metodami dálkového průzkumu mají v porovnání s tradičními postupy získávání poznatků jiné charakteristiky. Především je to georeference identifikovaných komponent (jíž předchází jejich ortorektifikace), která je většinou díky dobře patrné hranici mezi výškou a zbarvením plodin rostoucích nad půdorysy pohřbených objektů a mimo ně přesně určitelná buď v zeměpisných koordinátech, či v rovinném souřadnicovém systému. Jako body či polygony lze tyto komponenty analyticky zpracovat v digitálním prostředí, dnes převážně pomocí GIS. Celkovou velikost plochy zaplněné komponentami sice většinou nelze stanovit, nicméně prostřednictvím vegetačních příznaků máme k dispozici celkový půdorys konkrétní části jednoho sídelního areálu (případně několika sídelních areálů, které se překrývají) a můžeme na něm určit jeho kvalitativní a kvantitativní složení, tedy druhové zastoupení jednotlivých objektů, jejich vzájemný prostorový vztah a jejich příslušnost k jednomu a témuž sídelnímu areálu. Soubor takovýchto komponent lze využít k dalším analýzám. Výsledky leteckého průzkumu prováděného systematicky po dobu alespoň několika let tedy ve srovnání s pramennou základnou shromažďovanou dlouhodobě tradičními postupy potvrzují husté pravěké osídlení mnoha poloh. Zároveň nás informují o tom, jakými druhy a jakým počtem objektů jsou tyto polohy zaplněny (viz *obr. 2*).

Fenoménu vegetačních příznaků si lidé všímali odedávna. Poprvé byly zmíněny roku 1541 v díle anglického starožitníka

J. Lelanda (*Fagan 1959*) a jako projev indikující přítomnost pod povrchem ukrytých reliktů antropogenního původu byly interpretované o půl století později W. Camdenem (*Wilson 1996*, 42–43). Ve střední Evropě, konkrétně v Čechách, bylo pozorování porostových příznaků poprvé zaznamenáno v polovině 19. století, kdy K. V. Zap referoval o tomto jevu v souvislosti s popisem areálu bojiště u Kolína, kde ztotožnil místa s projevy porostových příznaků s hroby vojáků padlých v jedné z nejkrvavějších bitev Sedmileté války (1756–1763; *Zap 1855*; k záznamům o výskytu porostových příznaků před rozvojem letectví viz též *Benson – Miles 1974*; *Schmidt 1893*, 244–247; *Pič 1903*, 9). Od 20. let minulého století je problematika vegetačních příznaků, jakožto v evropském prostoru zdaleka nejčastěji využívaných indikátorů památek pohřbených pod zemí, předmětem trvalého odborného zájmu (*Crawford 1929*; *Riley 1946* a *1983*; *Jones – Evans 1975*; *Stanjek – Fassbinder 1995*; *Palmer 1996*; *Bewley 1996*; *Wilson 2000*; *Barber 2011*, 111–127).

3. První krok: zpracování lokalit detekovaných prostřednictvím vegetačních příznaků do podoby vektorizovaných plánů (*obr. 6–9*)

Od nástupu praktické implementace GIS do archeologie v 90. letech minulého století ovlivnil způsob mapování především britský *National Mapping Programme* (NMP, dnes pod označením *Historic England Aerial Investigation and Mapping* – https://historicengland.org.uk/research/results/reports/46-2019*)*, založený na analýze leteckých fotografií a archeologické interpretaci vegetačních příznaků na nich zachycených (*Horne 2009*; k projektům předcházejícím NMP viz *Stoertz 1997*; *Palmer 1984*). Stal se inspirací dlouholetého programu leteckého průzkumu, který je od roku 1992 součástí vědecko-výzkumné agendy pražského Archeologického ústavu AV ČR. Využít potenciálu tohoto – dnes již plně digitalizovaného a na internetových stránkách Digitálního archivu Archeologické mapy ČR (https://digiarchiv.aiscr.cz/) zveřejněného – souboru znamená převést metodou vektorizace interpretované šikmé letecké snímky pohřbených archeologických lokalit do podoby digitalizovaných plánů umístěných ve formě vektorové vrstvy v prostředí GIS. Tímto postupem získávají informace uložené na letecké fotografii stejnou kvalitu, jaká je požadována od dokumentace nemovitých archeologických objektů při terénních odkryvech – známe jejich přesnou velikost, tvar, rozměry a vzájemné prostorové vztahy (*Malina 2020*; *Gojda et al. 2022a*).

Velkou výhodou je v současnosti možnost pracovat při rektifikaci s ortofotomapami z prostředí mapových portálů. Lze využít větší množství na nich zachycených objektů, které mohou posloužit jako referenční body a také je zde nemalý počet lokalit v podobě porostových příznaků zachycen a zviditelněn. Optimální možností je pak s pomocí georeferencovaných leteckých měřických snímků a ortofotomap provádět rektifikaci v prostředí GIS. Na jejich podkladě jsou rektifikovány šikmé snímky a do samostatné vrstvy následně může být digitalizován (resp. vektorizován) jejich archeologický obsah. Tímto způsobem lze kombinovat plány všech fotoletecky zachycených lokalit, které je možné následně prohlížet na podkladu topografických map nebo leteckých či družicových ortofotomap dostupných v GIS prostřednictvím mapových služeb (WMS). Zároveň při tomto procesu vzniká evidence jednotlivých objektů zachycených na snímcích, včetně vlastního metadatového popisu. Taková data jsou použitelná nejen jako podklad pro mapování, ale též jako primární data pro výzkumné účely.

Finálním produktem celého tohoto procesu je podrobná 2D mapa archeologických lokalit, na níž jsou zachyceny půdorysy všech pod zemí ukrytých, ale díky vegetačním příznakům zviditelněných, objektů. V projektu ARÚ bylo dosud takto zmapováno 230 lokalit.

4. Druhý krok: produkce 3D obrazů lokalit s porostovými příznaky pomocí vícesnímkové (letecké) fotogrammetrie (*obr. 10*)

Oproti předchozím analogovým výstupům vneslo zavedení digitálních technologií do letecké archeologie zcela novou dimenzi, kdy se finální data stala trojrozměrnými, multifunkčními a virtuálními. Rozšíření tradičního prezentačního rámce o virtuální prostor vytvořilo podmínky i pro změnu systému a metod prezentace archeologických kontextů porostových příznaků.

Paralelně s transformací objektů archeologického zájmu do polygonů vektorové vrstvy digitální archeologické mapy dochází k pořizování 3D obrazů vybraných lokalit. Ty slouží k detailnějšímu poznání konkrétních charakteristik vegetačních příznaků dokumentované lokality a také k získání celkově podrobnější vizuální představy o lokalitě, resp. o její topografii (*Stal et al. 2013*; *Remondino 2011*; *Ioannidis et al. 2000*).

Pro převod vizuální stránky lokalit s porostovými příznaky do digitální trojrozměrné podoby byly primárně zvoleny metody Image Based Modelling a Structure from Motion (SfM), využita byla částečně i data z laserového leteckého skenování v kombinaci s leteckým snímkováním. Nedávný rychlý vývoj především v oblasti UAV (k využití dronů v archeologickém průzkumu viz např. *Risbøl – Gustavsen 2018*; *Themistocleous et al. 2015*) a optimalizace softwarového řešení pro SfM poskytly možnosti pro komplexní, rychlé a cenově dostupné zpracování i rozlehlých archeologických lokalit či větších krajinných celků (*Westoby et al. 2012*).

Při dokumentaci lokalit s porostovými příznaky ve středních a severozápadních Čechách bylo použito snímkování jak pomocí UAV, tak prostřednictvím šikmého snímkování zrcadlovým fotoaparátem z letadla. Pro potřebu detailnějšího zachycení celé lokality nebo její části bylo použito snímkování z dronu DJI Mavic PRO disponujícího 4K kamerou s možností pořizování 12Mpix snímků. Ruční snímkování z letadla bylo použito pro celkové zachycení krajinného rázu potřebného pro pochopení situování lokality na konkrétní georeliéf nebo v případě větší rozlohy dané lokality. Lokalita tak byla obvykle nalétnuta v kruhu se středem v místě zájmu a bylo pořízeno několik desítek fotografií z úhlu daného náklonem letadla. Použita byla zrcadlovka Nikon D2 s rozlišením 13 Mpix/snímek a vyzkoušeno bylo i fotografování z kamery GoPro HERO 5 s rozlišením 12 Mpix/snímek, jejíž stabilizační mechanismus dokonale eliminuje otřesy způsobené letovými podmínkami.

Zpracování získaných fotografií probíhalo v softwaru Agisoft Photoscan Professional. Při zpracování ručního snímkování z letadla bylo vloženo několik referenčních bodů, u kterých šlo odečíst prostorové souřadnice z některých volně dostupných webových stránek. U fotografií z UAV byl využit přímý import prostorových souřadnic jednotlivých snímků z GPS dronu, což pro dané účely poskytuje dostatečnou topografickou přesnost (*Carbonneau – Dietrich 2017*). Tento postup byl zvolen především z praktických časových důvodů (omezená doba, kdy jsou porostové příznaky pozorovatelné). Některé lokality nebyly ani fyzicky navštíveny (při snímkování z letadla).

Výsledný digitální 3D model dané lokality byl vyexportován v některém z obvyklých formátů včetně textury (OBJ, FBX, 3DS), umožňujícím jeho další úpravy ve 3D modelovacích softwarech (Blender, Sketchup). Případně probíhalo další workflow rovnou v renderovacím softwaru Lumion, kde byla do digitálního modelu terénu přidávána další data ve formě počítačových rekonstrukčních modelů. V prostředí softwaru Lumion bylo také možné dále pracovat s materiály pro zvýraznění porostových příznaků a další výhodou byla i možnost simulace různých světelných podmínek. Zde také proběhl render statických obrazů nebo videa, který byl dle situace doplněn dalšími efekty typu rozfázování animací, pohybu částí modelu, změn variant modelu atd. Finální video postprocessing byl vytvořen v programu Corel VideoStudio, který kromě obvyklých funkcí (jako je střih či časování videa) umožňuje přidávání dalších grafických prvků včetně textu.

5. Závěrečný krok: vytváření animovaných 3D rekonstrukčních modelů komponent archeologického dědictví zviditelněných porostovými příznaky

5.1. 3D počítačové rekonstrukce

Archeologické prameny nejsou jednoduchým odrazem lidských dějin, neboť informace, které o minulých kulturách podávají, jsou velice silně zkreslené jak po stránce kvalitativní, tak i kvantitativní (*Neustupný 1986*, 528). Jsou ze své podstaty vždy neúplné, což velice komplikuje snahu o jejich interpretaci, a tím pádem i o rekonstrukci a vizualizaci. V souvislosti s tvorbou trojrozměrných počítačových rekonstrukcí archeologických situací je potřeba vzít v potaz termín tzv. „nejistoty v datech“ a možnosti zobrazení této nejistoty ve vizualizacích.

Hlavní faktory kontextové i prostorové nejistoty mohou být zapříčiněny druhem dostupných dat, jejich úplností, spolehlivostí a interpretací, přičemž ve vizualizacích se hlavní problémy týkají geometrie, umístění, stáří, barvy, textury, materiálu, konstrukce, kontextu a krajiny (*Brusaporci 2017*). V rekonstrukčním modelu jsou nejistotou ovlivněny tři oblasti – tvar, materiál a vzhled (*Apollonio 2016*, 177). Metody, jak vizuálně označit nejistá data v počítačových rekonstrukcích, byly v dosavadních projektech řešeny obvykle označením těchto informací pomocí barevné škály, smíšené průhlednosti, kombinací barevné stupnice a průhlednosti nebo použitím různého vykreslení povrchu modelu.

Obsah modelu je obecně založen na metadatech, která jsou popisem technických aspektů, a na paradatech, která zahrnují systematiku rozhodování a interpretace – obě složky jsou zásadní pro získání konkrétní stupnice nejistoty (*Brusaporci 2017*, 67–68). Deskripce i kritických údajů, subjektivních rozhodnutí a představ umožní v pozdější analýze zhodnotit škálu možných interpretací (*Bruschke – Wacker 2016*, 257). Přeskočení tohoto procesu může značně znevěrohodnit vědecké poznatky, ze kterých se vycházelo, a hodnotu celého rekonstrukčního modelu. Systematická klasifikace technik vizualizace nejistoty (*Pang – Wittenbrink – Lodha 1997*) zahrnuje přidání piktogramů, upravení geometrie, atributů, animace a zvuku a navrhuje použití různých vizuálních podnětů podle toho, jestli jde o data numerická, vektorová nebo kategorická.

5.2. Postup tvorby a prezentace 3D počítačových rekonstrukcí

3D počítačový model studovaného území určený pro import do prostředí grafických softwarů byl proveden ve fotorealistickém stylu a obsahoval vysokou míru detailu. Jeho použití teoreticky znamená vysokou jistotu, že geometrie a vzhled objektu jsou rekonstruovány na skutečných naměřených datech, a v kombinaci s dalšími grafickými styly je tento postup přijímán i odbornou obcí (*Bakker – Meulenberg – Rode 2003*, 161; *Olivito – Taccola 2014*, 182).

Na fotogrammetrický model založený na skutečnosti lze umístit jednoduché geometrické nebo texturově odlišitelné objekty, které představují neexistující struktury. Je zde tak ihned zřetelný rozdíl mezi fotorealistickými částmi s vysokou mírou detailů, a tím pádem i vysokou jistotou dat, a mezi abstraktními domodelovanými částmi.

Tvorba počítačových modelů rekonstrukcí jednotlivých nemovitých struktur byla založena především na dostupných informacích pro dané období, kdy podoba nadzemních částí vycházela z interpretací archeologických výzkumů identické časové periody v daném regionu. Bylo přihlédnuto k již provedeným kresebným rekonstrukcím obdobných objektů od různých autorů, pokud byly k dispozici. Dále proběhlo porovnání s daty z experimentální archeologie a byly využity dostupné historické analogie.

Aby finální vizuální výstupy z provedených 3D počítačových rekonstrukčních modelů nezůstaly pouhými „hezkými ilustracemi" (*Reilly 1991*) degradujícími 3D vizualizace na pouhé umělecké dílo (*Barceló 2001*; *Sanders 2012*), byly jako hlavní výstupy zvoleny video animace.

Ve většině případů byl zvolen koncept, kdy je v úvodu použita forma „fly through videa", tedy pohyb kamery nad zájmovým územím z leteckého pohledu, aby byly zřetelné nejen sledované porostové příznaky, ale aby bylo zřejmé i umístění dané lokality v krajině. Dále jsme graficky zvýraznili zájmové území, či jednotlivé porostové příznaky. Když byly k dispozici výsledky z archeologického průzkumu lokality, byly do digitálního modelu na patřičné místo vloženy plány z terénního výzkumu či geofyzikální prospekce. V jednom případě se podařilo vložit i 3D fotogrammetrický model identického objektu nasnímaného na záchranném výzkumu ve stejném regionu. Animace počítačové rekonstrukce sledovaných objektů byla vytvořena tak, aby byl patrný samotný postup tvorby rekonstrukčních modelů, forma jejich zasazení do terénu a jejich základní konstrukční prvky. Odborníkům to umožňuje posoudit správnost interpretace a provedení dané 3D počítačové rekonstrukce, laickému divákovi tento přístup umožní snadněji pochopit jejich konstrukci a funkci.

6. Virtuální 3D rekonstrukční modely vybraných lokalit (*obr. 11–20*)

V rámci projektu *Archeologie z nebe*, řešeného Archeologickým ústavem AV ČR v letech 2018–2022 a finančně zajištěného z grantových fondů Ministerstva kultury v programu na podporu aplikovaného výzkumu a vývoje národní a kulturní identity (NAKI II; identifikační číslo: DG18P02OVV058), bylo v Česku poprvé uplatněno cílené snímkování vybraných archeologických nalezišť zviditelněných vegetačními příznaky, jehož účelem bylo metodou vícesnímkové fotogrammetrie vytvořit trojrozměrné modely vybraných lokalit a následně na jejich základě vytvořit jejich 3D počítačové rekonstrukce. Obsahem této kapitoly je přehled základních informací o deseti lokalitách zpracovaných výše uvedeným postupem. Při sestavování seznamu lokalit jsme především chtěli, aby v něm figurovaly areály různorodého stáří a funkce a projevující se pouze nepřímo – díky odlišným charakteristikám zemědělských plodin rostoucích nad jejich půdorysy a mimo ně.
Jedná se o tyto lokality:

- pravěká venkovská sídliště: **Straškov** (okr. Litoměřice; *obr. 8, 11*), **Račiněves** (okr. Litoměřice; *obr. 3, 12*);
- pravěké sídliště a pohřební areál: **Ctiněves** (okr. Litoměřice; *obr. 9, 13*);
- hradiště – pravěké a raně středověké ohrazené (opevněné) sídlo: **Přerovská hůra** (okr. Nymburk; *obr. 14*);
- pravěký rituální/ceremoniální (?) areál ohrazený dvojitým příkopem: **Kly** (okr. Mělník; *obr. 15*);
- pravěké (mohylové?) pohřebiště: **Černouček** (okr. Litoměřice; *obr. 16*);
- raně středověký venkovský ohrazený areál (dvůr/curtis/curia?): **Ledčice** (okr. Mělník; *obr. 17*);
- novověká polní opevnění: **Poplze** (okr. Litoměřice; *obr. 18*), **Hořín** (okr. Mělník; *obr. 19*), **Třeboutice** (okr. Litoměřice; *obr. 20*).

Animované 3D rekonstrukce těchto lokalit jsou dostupné na https://youtube.com/playlist?list=PL7b9FwaRRVBNt4AN4L2sscLvro4fCC6lo.

7. Vyhodnocení důvěryhodnosti počítačových animací

Jakkoliv je vizualizace silnějším vyjádřením ve srovnání s textem, její vysvětlující hodnota může být bez řádné deskripce postupu tvorby modelu přece jen menší. Pokud vizualizace jasně nekomunikuje proces svého vzniku, nezáleží na tom, jak byly pokládány výzkumné otázky, jak pečlivě byly studovány a interpretovány dostupné informace a jak náročně nebo kreativně je rekonstrukce zpracována. Vedle samotné tvorby vizualizace hraje významnou roli i dokumentace toho, jak je o jednotlivých komponentách modelu rozhodováno. Důležitost dokumentace tohoto postupu je zásadní pro zajištění úrovně transparentnosti (*Brusaporci 2017*).

Pro vybrané video animace jsme se pokusili vyjádřit jejich důvěryhodnost prostřednictvím tabulky (*tab. 1*), která zahrnuje metadata i paradata zobrazovaných scén. Hodnotící systém nabízí výběr ze tří variant. Dle zvolené možnosti je každému z deskriptorů přiřazena hodnota 100, 50 nebo 0, údaje jsou sečteny a jejich zprůměrováním vznikne finální vyjádření důvěryhodnosti dané počítačové scény v procentech.

Tabulka 1 obsahuje tři základní části: první část (1–4) je věnována vyhodnocení dostupných dat použitých při budování digitální scény areálu s porostovými příznaky, druhá část (5–8) kvantifikuje data nezbytná při tvorbě počítačových rekonstrukcí archeologických objektů a v třetí části (9–10) je zohledněno, zda video splňuje požadavky zobrazování digitálních rekonstrukcí dle mezinárodních úmluv.

8. Diskuze

Oproti slovnímu nebo textovému sdělení je vizuální komunikace mnohem efektivnější formou, neboť pracuje rychleji, paralelně a mnohorozměrně (*Hrbek 1968*, 551). Právě tím, že vizualizace umožňují výrazně urychlit celý proces poznávání, mají velký význam pro využití ve výuce, vědě a její popularizaci. Toto zrychlení kognitivního procesu je velice žádoucí specificky v dnešní době, kdy v přívalu velkého množství informací dochází k limitaci lidských schopností tato kvanta smysluplně třídit a organizovat (*Nevěřilová 2004*, 4).

Vizualizace dat ve vědě je prostředkem k poznávání a pochopení dosud neznámých skutečností, čímž se odlišuje od obvyklé prezentační grafiky, která zobrazuje již známé informace a je pouhým prostředkem ulehčujícím komunikaci. Vizualizace vědeckých dat je

Tab. 1. *Největší důvěryhodnost dosahují lokality především díky komplexní dálkové dokumentaci (dron, letadlo, více sezón) ve spojitosti s daty z provedených průzkumů (terénní výzkum, nedestruktivní průzkum). Pokud je vhodně provedena i 3D počítačová rekonstrukce, lze dosáhnout hypotetické důvěryhodnosti počítačové animace dané lokality dosahující až 80 %.*

	Straškov	Račiněves	Přerovská hůra	Kly	Černouček	Ledčice
1. Nalétnuto dronem	100	100	0	0	100	100
2. Použití snímkování z více sezón / vstupů	100	100	100	100	0	100
3. Využití LiDARu	0	0	100	100	0	0
4. Použití plánů GIS	100	100	0	0	0	100
5. Použití výsledků z terénního arch. výzkumu	100	0	0	100	100	100
6. Použití výsledků z nedestruktivního průzkumu	0	0	0	100	100	100
7. Identifikace porostových příznaků	100	100	50	100	100	100
8. Známé analogie	100	50	100	50	100	50
9. 3D rekonstrukce graficky odlišená	100	100	0	0	0	100
10. 3D rekonstrukce rozfázovaná	100	100	0	0	100	50
Důvěryhodnost	**80 %**	**65 %**	**35 %**	**55 %**	**60 %**	**80 %**

oproti tomu nástrojem usnadňujícím jejich syntézu, analýzu i interpretaci a metodu zkoumání (*Sochor et al. 1997*).

V oblasti informačních technologií je vizualizace metodou užívanou pro přetváření symbolů do geometrického rozměru, který umožňuje provádět další simulace a výpočty. Pokud operujeme s objekty, které jsou příliš složité, neuchopitelné nebo existují pouze v naší mysli, je mimořádně žádoucí vytvářet jejich vizuální modely, které slouží k lepšímu pochopení jejich konstrukce, organizace či proměn. Modelováním vznikají analogie k reáliím, které skutečnou vizuální podobu nemají, což se týká především vícerozměrných neexistujících struktur nebo v čase se proměňujících objektů (*Nevěřilová 2004*).

Prezentované výstupy jsou zaměřeny nejen na odbornou komunitu, kdy je koncept video animací nasměrován i k prezentaci tvrdých dat a výstavbě expertní vizualizace, ale i na laickou veřejnost, kdy je kladen důraz na vzbuzení přirozeného zájmu o dané téma a snadné pochopení zobrazovaných informací. Koncept dále vychází i z toho, že výstupy budou primárně prezentovány na digitálních médiích a internetu, kde má vizualizace pouze pár sekund na to, aby upoutala pozornost diváka. Zvolili jsme proto vždy krátkou formu videa, rychlou frekvenci střídání scén a využití pohybu v animacích.

9. Závěr

Zpracování analyzovaných a interpretovaných leteckých fotografií pořizovaných během aktivního leteckého průzkumu z malých výšek do podoby ortorektifikovaných a georeferencovaných map a podrobných plánů jednotlivých lokalit lze nepochybně chápat jako nejdůležitější krok v procesu jejich zhodnocení jak z hlediska péče o archeologické dědictví, tak s ohledem na jejich další využití ve výzkumu. Fondy archivu leteckých snímků Archeologického ústavu AV ČR budou proto i nadále zpracovávány tímto způsobem a v transformované podobě map a plánů se stanou integrální součástí Archeologické mapy ČR (www.archeologickamapa.cz) – platformy centrálního Archeologického informačního systému ČR (http://www.aiscr.cz). Produkce dosud zhotovených (video) animovaných virtuálních rekonstrukčních modelů archeologických lokalit detekovaných prostřednictvím porostových příznaků významně obohacuje možnosti, jak formou digitálně zpracovaného 3D obrazu vyjádřit archeologickou interpretaci někdejší podoby památek. I proto by vytváření 3D rekonstrukčních modelů mělo najít své pevné místo v oborovém instrumentáři.

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