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4D visualisation of an archaeological site: A case study from the Upper Paleolithic site of Milovice IV, Czech Republic

4D vizualizace archeologického naleziště: případová studie z mladopaleolitické lokality Milovice IV, Česká republika

– *Filip Hájek*, Martin Novák* –

KEYWORDS

Virtual archaeology – photogrammetry – digital archaeological reconstruction – 3D archaeological modelling – 4D spatio-temporal visualisation – site management – excavation methodology – Upper Paleolithic – Milovice IV – Czech Republic

ABSTRACT

The paper discusses using three-dimensional (3D) models in archaeological research and their combination for four-dimensional (4D) visualisation. The acquisition of 3D models during an archaeological excavation provides high-accuracy records of sites, entire find situations, and individual archaeological features or finds, allowing for their further exploration, study, and analysis at any time. When combined with GIS, 3D models can allow spatial and volumetric analyses, revealing site formation processes. With time as an additional dimension, their combination can also allow site reconstruction and spatio-temporal analysis, providing a perspective on the diachronic evolution of the site. Such use, in the sense of 4D visualisation, can markedly enhance the interpretation of archaeological data. The case study focuses on the multi-layered Upper Paleolithic site of Milovice IV in the Pavlov Hills region of South Moravia, Czech Republic, where 3D data recording was incorporated into the excavation processes. The paper evaluates the effectiveness of 4D mosaics delivered by merging separate 3D models. It turns out that 4D site-scale mosaics, obtained by merging separate models, encounter certain obstacles and are unsuitable for detailed visualisation and interpretation. Conversely, small-(excavation squares)-scale 4D mosaics can more vividly demonstrate the diachronic development of a site, the spatio-temporal relationships between artefacts, and the fieldwork workflow. It is also apparent that the 2D presentation of 4D models has limitations, and thus, other forms of presentation, kept within the virtual space, could better utilise all the benefits of spatiotemporal visualisations.

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1. Introduction

The visualisation and representation of archaeological data is an important aspect of any archaeological research. The ability to observe the data from different perspectives may develop their interpretation by facilitating the comprehension of large amounts of data, highlighting problems in data quantity, promoting the perception of unanticipated emergent properties, understanding spatial relations among archaeological entities and other features, and may even raise further research questions and aid in the formulation of hypotheses (Reilly 1991, Ware 2004, Frischer 2008, Campana 2014, Dell'Unto 2014). Apart from scientific work, the results of any research are supposed to be presented to the general public. With the right set of tools, the presentation of scientific data may lead to a better understanding and even increase interest, prestige, and funding for further research. Two-dimensional representations of archaeological data, such as photographs, plans, maps, and drawings, have been used since the dawn of this scientific discipline. The developments in information and digital technologies in the second half of the 20th century led to the development of digital space, which enabled researchers to integrate three-dimensional modelling (3D) and to represent and study their data in virtual space.

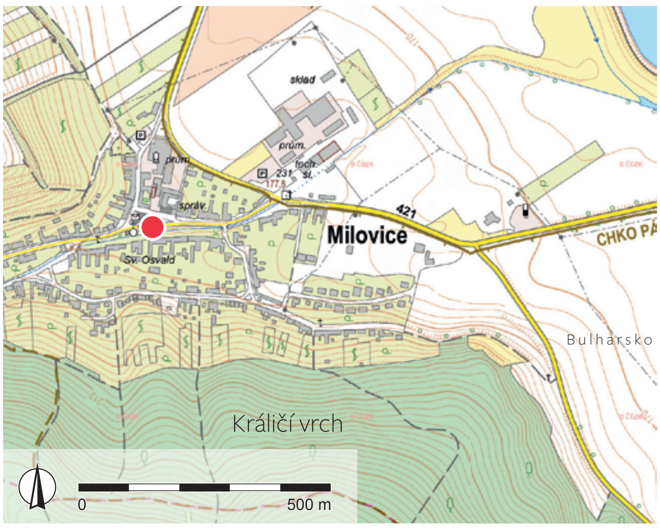

Fig. 1. The location of the Milovice IV site (marked with red). Map source: © ČÚZK; modified by F. Hájek.

Obr. 1. *Poloha lokality Milovice IV (vyznačeno červeně). Mapový podklad: © ČÚZK; upravil F. Hájek.*

3D models, i.e. three-dimensional representations of an object/area, enable researchers to record with high accuracy any entity, from small-scale objects and single artefacts up to large-scale objects, buildings, sites, or even landscapes. Although the first computer-based 3D models were already introduced in archaeology in the 1970s (Wilcock 1973; Frischer 2008), their potential for improving archaeological data visualisation started to be truly discussed in the 1990s (Reilly 1991). Nevertheless, it is only in recent years that 3D representations have become frequently used, owing to the rapid developments in digital technologies and the reduction in the price of 3D acquisition tools such as LiDAR, photogrammetry, and laser scanners (Arias et al. 2022).

Despite the irreversible nature of the investigation process, the incorporation of 3D data acquisition into the excavation methodology enables researchers to provide digital, high accuracy records and to 'visit', further explore, study, and analyse any site at any moment (Frischer 2008; Dell'Unto 2014). Therefore, 3D recording is frequently used at rescue excavations or at excavations of sites located in difficult to reach environments, for instance, underwater research and/or foreign campaigns. Recent developments in technology have provided archaeologists with the ability to acquire and process 3D data rapidly, even daily, which can be further used in site management, routine maintenance, and work planning (Dell'Unto et al. 2017; RodríguezGonzálvez et al. 2017). 3D models can also be applied in the monitoring of archaeological sites to detect interruptions of the site, either of natural or anthropogenic origin, and even to reveal the range of interruptions (Landeschi et al. 2016). Its combination with GIS enables researchers to merge the 3D models with other digitised data, making spatial analyses possible (Dell'Unto 2014). These 3D models can further be used for volumetric analysis, revealing the site formation processes (Dell'Unto et al. 2017, Landeschi 2019). Additional modelling and the combination of more 3D models may enable researchers to reconstruct the site (Elgewely, Wendrich 2016; Rodríguez-González et al. 2017; Rodríguez-Gonzálvez et al. 2019).

With time as an additional dimension, a combination of 3D models may provide 4D visualisation of the site and further spatio-temporal analysis (Campana 2014; Landeschi 2019). The basis of 4D models consists of four dimensions: x, y, z, and datum. The datum may represent either the date of the 3D model acquisition, which may further visualise the progress of excavation, or the date of loci, delivered from dated archaeological finds, and provide a perspective on spatio-temporal relationships among features of interest as well as a perspective on the diachronic evolution of the site (Rodríguez-Gonzálvez et al. 2017).

2. The site of Milovice IV

This article aims to demonstrate the use of 3D models at archaeological excavations and, more specifically, their combination for 4D visualisation. The case study concerns the site of Milovice IV, a multi-layered Upper Paleolithic settlement belonging to the Gravettian settlement area of Dolní Věstonice – Pavlov – Milovice (Svoboda 2020) in the Pavlov Hills region of South Moravia, Czech Republic (Fig. 1). Compared to the other sites in the area, the site is situated at a lower altitude, at the bottom of a Milovice side valley, beneath the centre of the present-day village (Fig. 1). The site was discovered in 2009 when an excavation of a limited area of 2.5 × 4 m in a collapsed old, abandoned cellar uncovered a complex of several archaeological layers from the Middle Gravettian (Svoboda et al. 2011). An additional rescue excavation in 2021 enabled exploration of another area measuring 6 × 4 m, spatially adjacent directly to the original 2009 excavation, located 4 m below the modern surface within the trench left by the collapsed cellar. A new excavation captured a much more complex microstratigraphy, indicating a more extended settlement history at the site, from the Early Upper Paleolithic (Aurignacian) to the beginning of the Late Gravettian (Novák et al. 2022). The Upper Paleolithic stratigraphic sequence was partially interrupted by the stone wall of the wine cellar and, on the upper horizon, by several pits (Fig. 2), presumably dated to the 19th century, based on the coins and pottery fragments found within them.

The 2021 excavation yielded an extensive collection of findings, including lithic artefacts, mineral dyes, faunal, malacozoological, and paleobotanical remains – nearly 2600 3D inventoried items – complemented by other numerous findings (tens of thousands) obtained during the wet sieving of cultural layer sediments. The finds were distributed across the entire excavated area in several stratigraphic sequences. Based on the preliminary state of the research (Novák et al. 2022), three distinct chronological horizons (AH I–III) were recognised during the excavation.

Fig. 2. Milovice IV. The excavated area, located 4 m below the recent surface, with a visible stone wall of a cellar and pits of the Industrial Age. Photo by Institute of Archaeology, Czech Academy of Science, Brno (ARÚB).

Obr. 2. *Milovice IV. Plocha výzkumu umístěna 4 m pod současným povrchem s viditelnou kamennou zdí zbytku vinného sklepu a jamkami z období vrcholného novověku. Foto Archeologický ústav AV ČR, Brno, v. v. i. (ARÚB).*

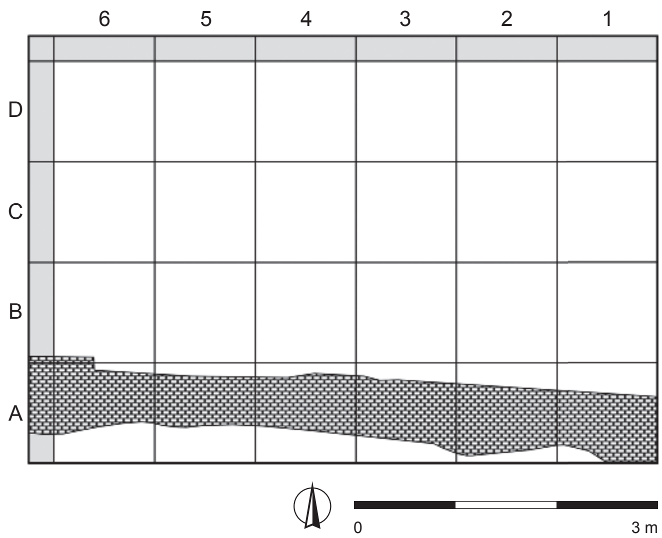

Fig. 3. Milovice IV. The plan of the excavated area. Graphic by M. Novák.

Obr. 3. *Milovice IV. Plán zkoumané plochy. Grafika M. Novák.*

Fig. 4. Milovice IV. 3D models with dimensions 1 × 2 m: A – squares C3 and D3 at depth level 35–40 cm; B – squares B3 and B4 at depth level 70–75 cm. Author F. Hájek.

Obr. 4. *Milovice IV. 3D modely o rozměrech 1 × 2 m: A – čtverce C3 a D3 na úrovni 35–40 cm; B – čtverce B3 a B4 na úrovni 70–75 cm. Autor F. Hájek.*

2.1 Archaeological Horizon I (10–30 cm depth level)

The upper find situation is defined by a smaller collection of lithic artefacts and dispersed skeletal remains of large and extra-large mammals. The position represents a periphery toss zone of the settlement and is most probably connected to a part of a larger mammoth bone deposit. According to the presence of significant microlithic implements, backed microblades with straight truncations could be assigned to the Late Gravettian.

2.2 Archaeological Horizon II (30–95 cm depth level)

The main cultural horizon, corresponding with the finding horizon of the 2009 excavation, falls into the Evolved Pavlovian (Svoboda et al. 2011). In some parts, it is divided into two sub-horizons, IIa and IIb, and presented by rich lithic and osteological assemblages, hard animal tissue artefacts and art, tertiary and quaternary molluscs, ochre, charcoals, and a hearth with red burned hearthstone slabs. Such findings and their distributions allow us to interpret the situation as part of a base camp settlement zone with a horse-hunting-oriented economy where activities connected to game skinning, butchering, nourishment, and production of lithic and organic artefacts took place.

2.3 Archaeological Horizon III (95–145 cm depth level)

The lowest layer contains a small number of lithic artefacts vertically dispersed in the soil horizon below the Last Glacial loess, and occasional fragments of faunal remains were documented here. The lithic techno-typological features and used raw materials are strikingly different from those originating from the main layer above, and these findings are placed in the Early Upper Paleolithic to Aurignacian.

3. Methods

Standard methods for excavation Paleolithic find situations (e.g. Torre et al. 2014) were used during the 2021 excavation. The excavation area of 6 × 4 m was divided into 24 squares with a dimension of 1 m^2 (Fig. 3). Each square (A-D/1-6) was separately excavated in four sub-squares (a–d) and vertically documented every five centimetres. The vertical extent of the excavation reached a depth of 40–145 cm, measured from the bottom of the trench. Due to time constraints and bad weather, when heavy rains caused the trench to flood and parts of the profiles to collapse, excavating all the squares in full vertical range to the subsoil level was impossible.

Each square at each excavated depth level was photographically documented, and the coordinates of squares and finds were recorded by a total station in a three-dimensional X-Y-Z system. The 3D data were acquired by Structure from Motion photogrammetry. Squares at each depth level were georeferenced and photo-documented following the methodology suggested by Šindelář et al. (2019): a series of photographs taken in two circles and one photograph taken from the top. On average, about 30 photographs were taken for each square's depth level. The Nikon D5300 camera was used for photographic recording.

To ensure systematic documentation, all squares underwent comprehensive recording, including 3D data acquisition, immediately following the completion of the excavation work at each square and depth. As such, the progression of excavation within a specific square and depth was conditional on the prior acquisition of 3D data. At the same time, the squares were always tagged with a table detailing the photoset, including the square number and elevation level, which further facilitated the compilation process for constructing 3D mosaics. Additionally, squares were accompanied by a scale during the 3D data acquisition for a double-check of the dimensions during the merging process.

The 3D models were implemented in the recording methodology in order to document archaeological entities with high accuracy and in an attempt to record as much data as possible within the time of the rescue excavation. Therefore, the 3D models

Fig. 5. Milovice IV. Excavation process at the site, with each square excavated at a different time. Photo by ARÚB.

Obr. 5. *Milovice IV. Průběh výkopových prací na lokalitě, kdy jsou různé čtverce odkrývány v různý čas. Foto ARÚB.*

Fig. 6. Milovice IV. A – the depth level 25–30 cm (megafauna remains of AH I lying on the soils and finds of AH IIa); B – the depth level 60–65 cm (the dense faunal remains accumulation of AH IIb). Author F. Hájek.

Obr. 6. *Milovice IV. A – úroveň 25–30 cm (pozůstatky megafauny z úrovně AH I ležící na vrstvě a nálezech úrovně AH IIa); B – úroveň 60–65 cm (hustá kumulace zvířecích pozůstatků úrovně AH IIb). Autor F. Hájek.*

Fig. 7. Milovice IV. Merged 3D mosaics of depth levels 25–30 cm and 60–65 cm. Author F. Hájek.
Obr. 7. *Milovice IV. Sloučené 3D mozaiky úrovní 25–30 cm a 60–65 cm. Autor F. Hájek.*

were not processed and generated daily but during the post-processing period after the fieldwork was finished. Moreover, the 3D data were acquired predominantly from isolated squares and depth levels, apart from squares excavated to the same elevation at the same time with finds situated on both squares, and thus were acquired as isolated models, recording the stage as they were excavated *in situ*. Finally, due to the time pressure of rescue excavation, depth levels yielding no finds were documented only by a set of 4–6 images from the top for regular documentation, not for 3D processing, and thus were not georeferenced.

A total of 167 individual find situations were documented on the entire excavation area for further 3D processing. These recorded situations are usually represented by 1 × 1 m squares. Only occasionally squares were documented together, e.g. B3 and B4 at depth level 70–75 cm and D3 and C3 at depth level 35–40 cm, because they were unearthed at the same time and contained finds of the same archaeological context (Fig. 4).

The 3D models were generated and merged in Agisoft Metashape, version 1.8.4. This software enables not only the processing and generation of 3D models, but also their alignment, merging and visualisation. Since spatial, 3D or other analyses were not part of this work, no other software (such as GIS) was used. At first, photos from an isolated square were aligned, coordinates were assigned to GCPs, and a mesh was generated. To create horizontal and/or vertical mosaics, the edges and sections of the 3D models of isolated squares were cut in order to connect them to neighbouring square models at the same depth levels. The texture was generated after the model's undesired elements were removed. In order to accelerate the processing, more models were generated in a batch process. Single squares were processed as single chunks. Mosaics were created by aligning more chunks when the majority of the georeferenced models were placed at their location. Small offsets and non-georeferenced models were allocated manually, by moving and scaling the models.

4. 4D visualisation processing

4.1. Site-scale horizontal mosaics

The generated 3D models were merged in order to create mosaics both on the horizontal and vertical axes. When merging models on horizontal axes, the emphasis was put on following the stratigraphic sequences to provide an overview of the entire excavated area. These visualisations may provide a complex perspective on the entire depth level, which is, in most cases, not possible *in situ* during the fieldwork due to the excavation methods (Fig. 5). On the vertical axis, the priority was given to demonstrating the diachronic evolution of the site as well as the work's progress.

3D mosaics were created from models located slightly above the edges of the horizons, because when the edges were reached, most of the finds had already been removed. Furthermore, it is necessary to keep in mind that 3D models do not represent stratigraphic layers *per se* but rather the excavation progress. As the stratigraphy and spatial distribution of finds naturally do not follow the exact horizontal level, finds can be unearthed at the edge of the excavated layers and subsequently kept *in situ* by researchers for further recording in the following layers. This results in topographic anomalies on the models when recorded finds can be located above the excavated level. At the same time, selected depth levels for 3D mosaics were chosen based on the 'strength of evidence', i.e. the vertical distance from the edges of stratigraphic layers and the number of corresponding finds *in situ* and of the available 3D models.

3D mosaics were created for the depth levels 25–30 cm and 60–65 cm (Fig. 6). The combination of the thinness of AH I and the spatial extent of megafauna remains impeded the visualisation of AH I separately. Moreover, the considerable weight of some megafauna remains belonging to AH I dropped on the preceding layer AH IIa. As such, the mosaic of the level 25–30 cm depicts the megafauna remains of AH I lying on the soils and finds of AH IIa. The 3D mosaic of the depth level 60–65 cm enabled visualisation of the horizontal extent of the dense faunal remains accumulation, notably in squares B1–4 and C1–2, corresponding to the AH IIb. Additionally, the 3D mosaic of this level was supplemented with two models from adjacent levels, with square D3 at the level of 50–55 cm, as it refers to this specific horizon, and also, this square was not excavated deeper, and the squares B3 and B4 at 70–75 cm, where the concentration of bones was more exposed.

The last find horizon (AH III) was not visualised due to insufficient data. It was recognised only in the western part of the excavated area, in squares B–D/5–6, represented by the limited number of lithic artefacts. They were vertically distributed within the squares very sparsely with no apparent concentration, and the squares at these levels seemed sterile, so no 3D data were acquired from these bottom levels.

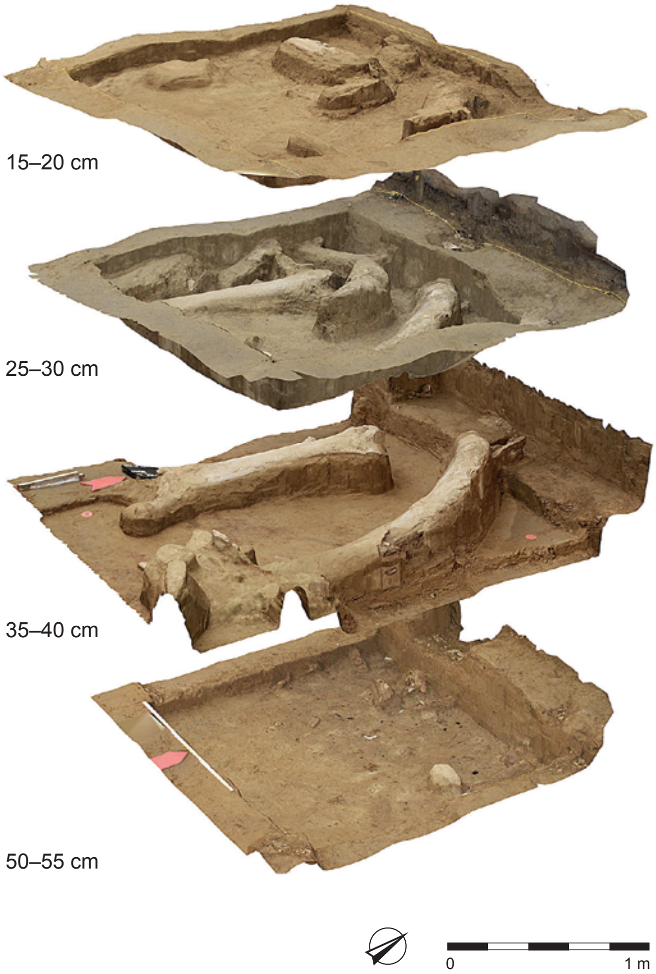

Fig. 8. Milovice IV. The sequence of depth levels in square D3 (1 × 1 m). Author F. Hájek.

Obr. 8. *Milovice IV. Sled úrovní ve čtverci D3 (1 × 1 m). Autor F. Hájek.*

As already outlined above, topographic anomalies may affect the connection between the models. It is less evident at the depth level of 25–30 cm but more apparent at 60–65 cm, as deeper trenches may suffer more from imperfect sections. Additionally, the 3D data were acquired during the entire excavation period, i.e. the 3D models were recorded at different times of day with different light conditions. This resulted in different colouring of the 3D models, which may mislead the interpretation of different stratigraphic layers. As 3D models had to be generated separately, the colour calibration could not be executed in a satisfying way. Moreover, due to the large area, the combination of both depth levels is not, in terms of visualisation and lucidity, effective and is rather confusing (Fig. 7). Thus, presumably, the best way to visualise them is next to one another (Fig. 6).

4.2. Square-scale vertical mosaics

In an attempt to visualise the diachronic evolution of the site as well as work's progress, the small-scale, or rather square-scale, vertical mosaics turned out to be significantly more illustrative. Vertical mosaics of squares D3 and B3 allow for changes to be seen through the eyes of an archaeologist working *in situ*. The square D3 depicts the changes in finds distribution at depth levels from 15–20 cm to 50–55 cm (Fig. 8). The first two depth levels correspond to AH I, depth level 35–40 cm shows the upper limit of AH IIa, while depth level 50–55 cm depicts the beginning of AH IIb.

B3 is represented by three squares: 25–30 cm, 70–75 cm, and 90–95 cm (Fig. 9). The depth level 25–30 cm depicts AH I, represented by a mammoth rib and molars. The concentration of horse osteological remains from AH IIb is recorded at the depth level 70–75 cm. Lastly, the depth level 90–95 cm represents the bottom of AH IIb, characterised by the ashy layer. For the purposes of the visualisation, the vertical distance between the squares was increased and thus the locations of the squares do not correspond to their true elevations.

A denser mosaic with true elevations further demonstrates the excavation progress within the single square, showing which finds were revealed within the square, which were kept *in situ* through more depth levels, and for how long. The 4D mosaic of square B4 depicts small-scale diachronic evolution and progress of excavation: the mammoth tusk, of AH I unearthed at level 25–30 cm was still kept *in situ* to the level 45–50 cm of AH IIa, as well as the mammoth rib kept in the eastern section. Further, the mosaic shows lower levels (60–65 cm and 70–75 cm) of AH IIb, containing depositions of other faunal remains (Fig. 10–12). At the same time, the models captured the recent interruptions of the site in the form of small pits of presumably Industrial age and their extent.

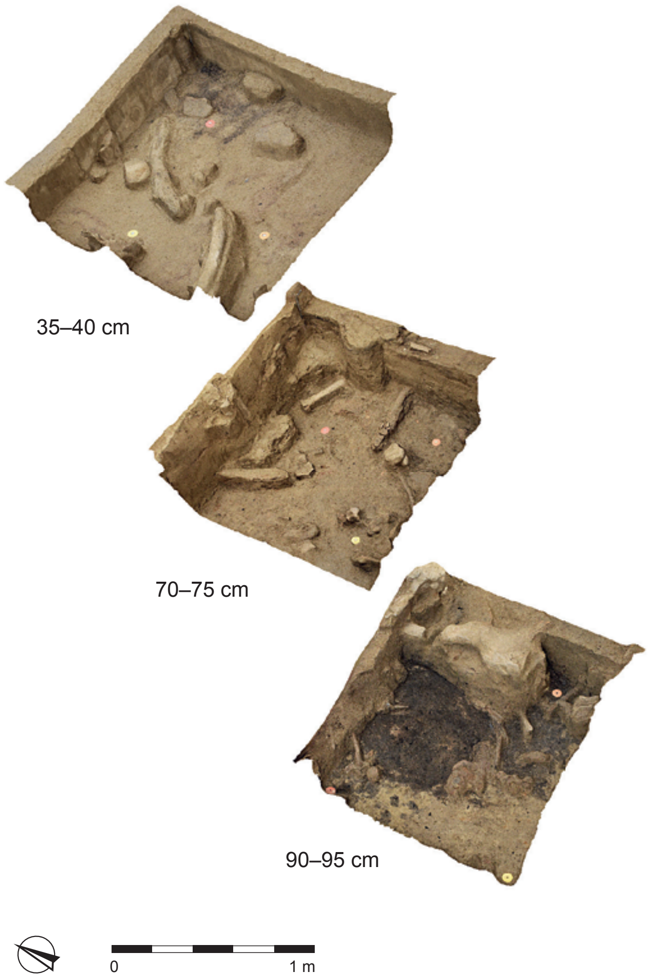

Fig. 9. Milovice IV. The sequence of depth levels in square B3 (1 × 1 m). Author F. Hájek.

Obr. 9. *Milovice IV. Sled úrovní ve čtverci B3 (1 × 1 m). Autor F. Hájek.*

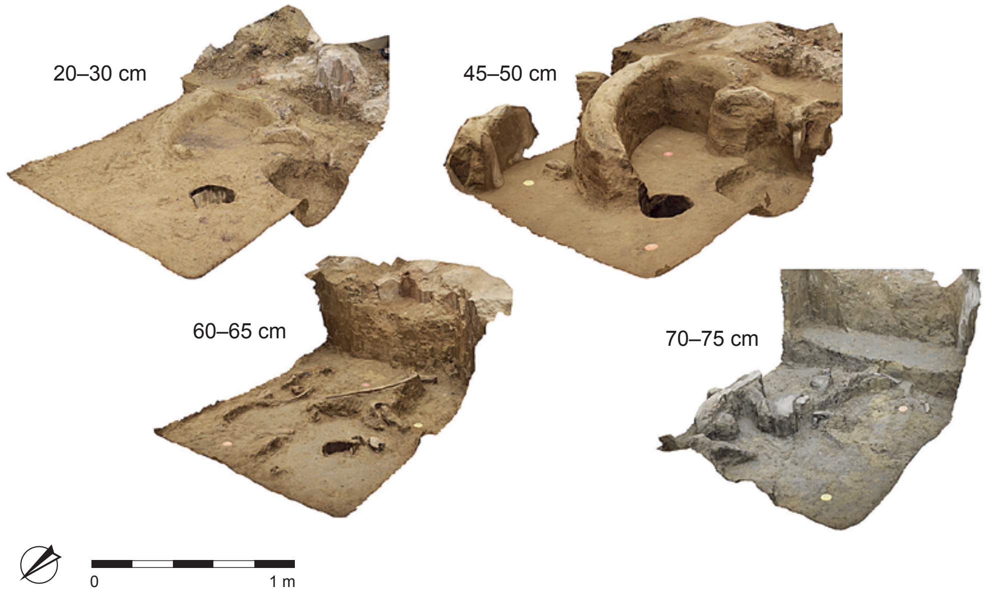

Fig. 10. Milovice IV. Isolated depth levels of square B4 (1 × 1 m). Author F. Hájek.

Obr. 10. *Milovice IV. Izolované úrovně ve čtverci B4 (1 × 1 m). Autor F. Hájek.*

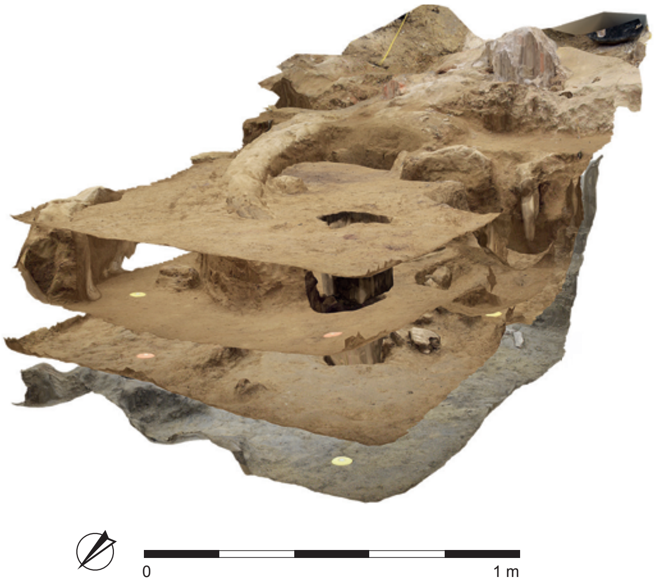

Fig. 11. Milovice IV. Merged selected depth levels of square B4 (1 × 1 m). Author F. Hájek.

Obr. 11. *Milovice IV. Sloučené úrovně ve čtverci B4 (1 × 1 m). Autor F. Hájek.*

5. Discussion

Through the processing of 4D mosaics, an important question has been raised: What is the most effective way of visualising 4D models? It turned out that 4D site-scale mosaics, delivered from merging separated 3D models, go hand in hand with several obstacles listed above, while small/square-scale mosaics may more illustratively demonstrate the diachronic evolution of the site as well as working progress. Small-scale visualisation was also applied by Dell'Unto et al. (2017) at the Neolithic site of Kämpinge. Pacheco-Ruiz et al. (2018) visualised a 4D model of a 2 × 2 m trench as the sequence of maps. On the contrary, a site-scale 4D model was created by Martínez-Fernández et al. (2020), who acquired 3D data by terrestrial laser scanner and from the entire area without the necessity of creating any mosaics.

It is apparent that site-scale 4D visualisations presented in 2D are not sufficiently illustrative, which may not stimulate the observer's understanding as originally intended. Therefore, other forms of data representation, such as those incorporating virtual space, could be more promising. 4D reconstructions created by several researchers (Elgewely, Wendrich 2016; Rodríguez-Gonzálvez et al. 2017; Rodríguez-Gonzálvez et al. 2019) within virtual space bore the ability to visualise the entire sites and buildings, though reconstructed sites are predominantly of historical age. So, what could be the most effective form of visualisation, or even reconstruction of the prehistoric site? As most of the prehistoric sites, especially those, as in this case, of Paleolithic age, do not consist of real structures but rather finds, distributed within a certain horizon of sediments, the workflow would suggest not incorporating 3D models of squares, or at least not to such an extent as in the current study, but rather georeferenced models of finds, visualised in GIS and distributed within vectorized 3D stratigraphic layers. Such a reconstruction could provide a sufficient perspective on the spatial distribution of finds within the site and their relations with stratigraphic layers and other features. Besides, such a reconstruction would better incorporate the stratigraphy of the site and facilitate further stratigraphic studies. Similar models were already created, for instance, by Ortega-Alvarado et al. (2022), who presented the 4D small-scale model, obtained by Tof technology, and even incorporated the finds in their original arrangement. Secci et al. (2021), paired 3D models of the shipwreck site with 3D models of lifted amphorae bearing sediment and biogenic horizon marks on their walls in order to reconstruct the environment and sedimentation processes at the site. However, it is necessary to keep in mind that suggested workflow incorporating 3D models of finds would be time consuming, especially given the large number of recovered finds that might be uncovered at an archaeological site.

6. Conclusion

The present study demonstrates that 4D visualisation can be delivered from mosaics of 3D models of squares with 3D data acquired during the entire time span of the excavation. Site-scale mosaics provide an overview of the whole excavated area at a certain depth level. However, their combination is less illustrative, and the best option is to visualise each layer separately. Furthermore, these mosaics at deeper elevations suffer from topographic

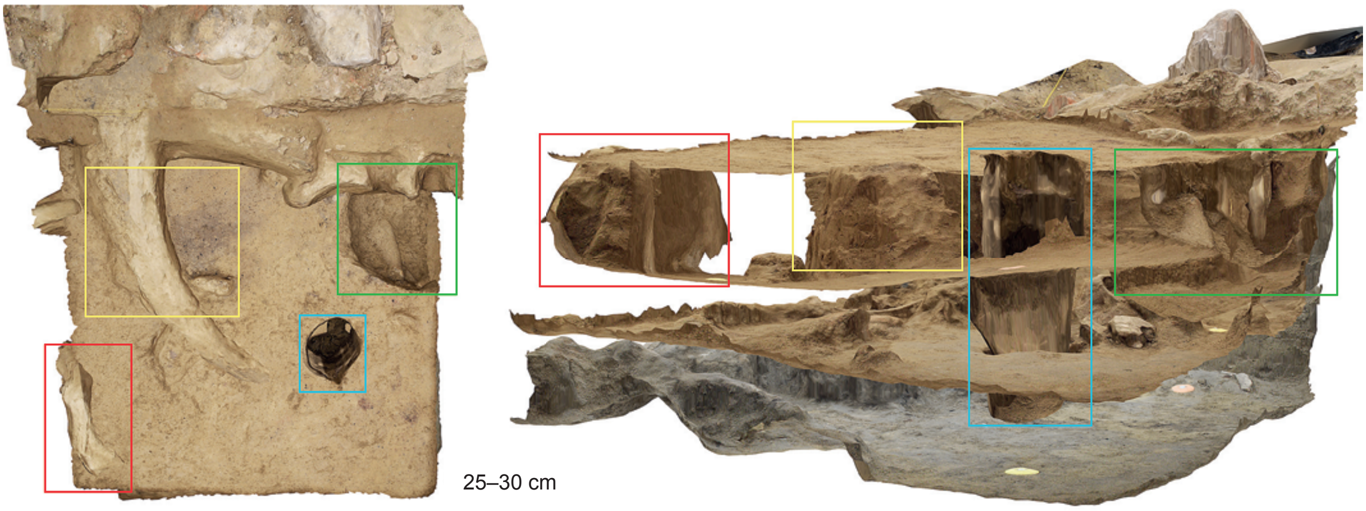

Fig. 12. Milovice IV. The extent of features across multiple depth levels in square B4: red square – fragment of a rib; yellow square – mammoth tusk; blue square – recent pit; green square – recent pit. Author F. Hájek.

Obr. 12. *Milovice IV. Rozsah prvků napříč vícero úrovněmi ve čtverci B4: červený čtverec – fragment žebra; žlutý čtverec – mamutí kel; modrý čtverec – recentní jamka; zelený čtverec – recentní jamka. Autor F. Hájek.*

anomalies and imperfect sections. Square-scale 4D mosaics turned out to be significantly more effective, owing to their ability to sufficiently illustrate the diachronic evolution of the site, spatio-temporal relations among finds within the site, as well as the work's progress. Moreover, a small-scale visualisation enables researchers to pinpoint the squares of significant value, or with sufficient amounts of 3D data, and thus illustratively demonstrate their findings. Lastly, it is apparent that 2D presentation of 4D models has limitations, and thus other forms of presentation, kept within the virtual space, could better utilise all the benefits of spatio-temporal visualisations.

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Summary

3D modely, tedy trojrozměrné reprezentace objektu/oblasti, umožňují s vysokou přesností zaznamenávat jakoukoli entitu, od malých objektů a jednotlivých artefaktů až po velké objekty, budovy, místa nebo dokonce celé krajiny. Navzdory nevratné a destruktivní povaze archeologických vykopávek umožňuje začlenění 3D dokumentace do metodiky výzkumu získat digitální záznamy s vysokou přesností a i zpětně tak kdykoli „navštívit", dále zkoumat, studovat a analyzovat jakoukoliv lokalitu, a to v libovolném čase a místě (Frischer 2008; Dell'Unto 2014). V kombinaci s GIS mohou 3D modely umožnit prostorové a objemové analýzy a odhalit procesy stojící za formováním lokality. Začleněním času jakožto dalšího rozměru je možné udělat časoprostorovou analýzu, která poskytuje pohled na diachronní vývoj lokality, i postup výkopových prací (Landeschi 2019).

Případová studie se zaměřuje na mladopaleolitické naleziště Milovice IV (obr. 1), nacházející se v gravettském sídelním areálu Dolní Věstonice – Pavlov – Milovice (Svoboda 2016). Poslední záchranný výzkum na lokalitě v roce 2021 (Novák et al. 2022) umožnil prozkoumat plochu o rozměrech 6 × 4 m (obr. 2), prostorově navazující přímo na původní výkop z roku 2009 (Svoboda et al. 2011). Nový výzkum zachytil mnohem složitější mikrostratigrafii, naznačující rozsáhlejší historii osídlení lokality, od starší fáze mladého paleolitu (aurignacien) do počátku mladého gravettienu (Novák et al. 2022). Výzkum poskytl rozsáhlou kolekci archeologických nálezů, včetně artefaktů štípané kamenné industrie, kousků minerálních barviv, archeozoologických, malakozoologických a paleobotanických pozůstatků, které byly rozmístěny po celé odkryté ploše ve třech chronologicky odlišných archeologických horizontech (AH I–III).

Plocha výkopu o rozloze 6 × 4 m byla rozdělena na 24 čtverců o rozměru 1 × 1 m (obr. 3). Každý čtverec (A–D/1–6) byl samostatně vyhlouben ve čtyřech dílčích čtvercích (a–d) a vertikálně dokumentován každých pět centimetrů. Vertikální rozsah výkopu dosahoval hloubky 40–145 cm. Každý čtverec v každé vykopané hloubkové úrovni byl fotograficky zdokumentován a souřadnice čtverců a nálezů byly zaznamenány totální stanicí v trojrozměrném systému X-Y-Z. 3D data byla získána vícesnímkovou fotogrammetrií. Čtverce v každé hloubkové úrovni byly georeferencovány a fotograficky dokumentovány podle metodiky navržené Šindelářem et al. (2019). Vzhledem k časové tísni záchranného výzkumu byly čtverce bez nálezů dokumentovány pouze sadou 4–6 snímků shora pro běžnou dokumentaci, nikoli pro 3D zpracování, a nebyly tak georeferencovány.

3D dokumentace byla implementována do metodiky exkavace za účelem zaznamenat co nejvíce dat v době záchranného výzkumu. 3D modely proto nebyly generovány na denní bázi, ale během období následného zpracování po dokončení terénních prací. 3D modely byly vygenerovány a sloučeny v Agisoft Metashape, verze 1.8.4. Modelům postrádajícím souřadnice musely být přiděleny ručně. Vygenerované 3D modely byly sloučeny za účelem vytvoření mozaiky na horizontální i vertikální ose.

Pro získání přehledu o celé zkoumané oblasti byl při slučování modelů na horizontálních osách kladen důraz na sledování stratigrafických sekvencí. Tyto 3D mozaiky byly vytvořeny pro AH I na hloubkové úrovni 25–30 cm a pro AH II na hloubkové

úrovni 60–65 cm. Pro AH III nebylo možné vytvořit mozaiku, protože nálezy z této vrstvy byly sporadické až izolované, a proto zdánlivě sterilní čtverce na této úrovni nebyly fotogrammetricky dokumentovány. Zároveň kvůli špatnému počasí a časovým okolnostem nebyly všechny čtverce prokopány až na požadovanou úroveň (>90 cm).

Z vytvořených mozaik (obr. 4–12) je patrné, že s přibývající hloubkou narůstají topografické odchylky a anomálie, pramenící z nerovností na profilech a nálezů překračujících vícero hloubkových úrovní. Kombinace mozaik celé plochy pro vytvoření 4D mozaiky nicméně naráží na určité překážky a není zcela efektivní pro detailní vizualizaci a interpretaci. Naopak, 4D mozaiky v malém měřítku (jednotlivé čtverce) mohou názorněji demonstrovat diachronní vývoj lokality, časoprostorové vztahy mezi artefakty a pracovní postup v terénu. Je také zřejmé, že 2D prezentace 4D modelů má svoje limity a lépší využítí všech výhod časoprostorových vizualizací by tak mohly nabídnout jiné formy prezentace, umístěné do virtuálního prostoru.

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