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Content

General information 5
1 Introduction 7
1.1 Mission 7
1.3 Awards and Careers 2021 8
1.4 Research Programme 8
2 Data acquisition and processing (DAP) 9
2.1 Geophysics 9
2.2 Extension of ApSoft 2.0 16
2.3 Image-based modelling 17
2.4 Terrestrial and airborne laser scanning 23
3 Data visualisation (VIS) 27
3.1 Fused relief visualisation 27
3.2 3D data visualisation 28
4 Integrated data interpretation (INT) 30
4.1 Bassianae 30
5 Data Management (DAM) 32
6 Data fusion (DF) 33
6.1 TAIFU 33
7 Semiautomatic feature extraction (FEX) 35
7.1 Denoising Filters 35
7.2 Segmentation 36
7.3 Interactive interpretation 37
8 Reconstruction and Simulation (SIM) 40
8.1 Open-source desktop planetarium *Stellarium* 40
9 Spatio-temporal reasoning (STR) 40
9.1 Harris Matrix Composer (HMC) 40
9.2 Harris Matrix Composer Plus (HMC+) 41
9.3 ArcMap Toolbox 42
10 Dissemination and awareness (DISS) 43
10.1 Press releases 43
10.2 TV productions 43
10.3 Exhibitions 44
10.4 Scientific publications and presentations 2021 47
11 Training and teaching (TRAIN) 53
11.1 Internal training 53

11.2 University field schools 53
11.3 Internships 55
11.4 University lectures 56
12 Third party funded research projects 57
12.1 Kleinhadersdorf 57
12.2 MAMUZ 58
12.3 Heldenberg 59
12.4 InfoSYS 60
12.5 Living Danube Limes 62
12.6 INDIGO 63
Appendix “Media Coverage 2021” 68

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Univie	University of Vienna (A) - Vienna Institute for Archaeological Science (VIAS) and Institute for Prehistoric and Historical Archaeology (UHA)
DUK	University for Continuing Education Krems (A)
ZAMG	Central Institute for Meteorology and Geodynamics – Applied Geophysics (A)
7reasons	7reasons Medien GmbH (A)
SRS	Spanish Riding School (A)
NIKU	Norsk Institut for Kulturminneforskning - The Norwegian Institute for Cultural Heritage – Digital Archaeology Department (N)
Vtfk	Vestfold and Telemark fylkeskommune (N)
LWL	Landesverband Westfalen-Lippe - Federal state archaeology of Westphalia-Lippe (D)

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1 Introduction

1.1 Mission

The mission of the Ludwig Boltzmann Institute for Archaeological Prospection and Virtual Archaeology (LBI ArchPro) is to research, develop, apply, and promote efficient non-invasive archaeological prospection, digital documentation, and virtual archaeology. The main objective of the LBI ArchPro, as currently supported by the LBG and a consortium of eleven European institutions and 32 collaborative partners (academic and dedicated research institutes, museums, heritage boards, SMEs and governmental bodies), is to be an internationally leading scientific institution for basic and applied research and development focussing on high-resolution archaeological prospection methods and technology, innovative digital archaeological documentation techniques and novel concepts of virtual archaeology.

The main motivation - based on the Valletta Convention - that is driving the LBI ArchPro approach is based on the societal necessity to develop efficient means for the reliable identification, documentation, interpretation, and comprehensive visualisation of buried and still standing archaeological heritage, which are under serious threat from destruction and continuous deterioration, natural hazards and lacking public awareness. The Valetta Convention as part of the Malta Treaty clearly states that non-destructive archaeological investigation methods should be used wherever possible – a recommendation that in practice still is mostly disregarded. However, our multidisciplinary research consortium considers this international treaty an important guideline and impetus for the advancement of future technologies and methods safeguarding and preserving our common cultural heritage. We are convinced that the large-scale application of non-invasive high-resolution archaeological prospection and digital documentation and the exploration of the resulting big 3D and 4D digital data sets, by means of virtual archaeology, are the most appropriate solutions for future archaeology. The proposed innovative approach provides archaeologists and planning authorities with the spatial information required for the protection and investigation of threatened buried and standing heritage at the appropriate scales. This approach integrates the scientific fields of remote sensing, geophysics, geomatics, computer sciences, and archaeological research.

The generation of awareness for the LBI ArchPro approach and the dissemination of generated research results to the scientific community, stakeholders and citizens alike are an important objective of the LBI ArchPro and its co-financing partners. To this purpose peer reviewed publications are prepared, international conferences and workshops organised and attended, as well as professional TV films produced, and frequent press releases disseminated. The potentials and possibilities that result from the research work of the LBI ArchPro are promoted in such a way that they become comprehensible in their relevance for political and administrative decisions, spatial planning, the building industry, creative industry, private as well as public research institutions. The implementation of standardised techniques and methods developed by the LBI ArchPro generate benefits and added value in cultural heritage management, education and in cultural tourism. A special focus is put on the development of unconventional ways and concepts for public dissemination. Measures to raise awareness for respective challenges and potentials of the digital age and the implementation of Open Science will be increased. This includes the aspect of education and training of the next generation of researchers and heritage managers, as well as the emphasis on the need for interdisciplinary research reflecting the importance of our common cultural heritage, extended archaeological sites and entire archaeological landscapes.

1.3 Awards and Careers 2021

The Queen' Anniversary Prize for Higher and Further Education (UK)

The University of Bradford has been awarded the prestigious "Queen's Anniversary Prize for Higher and Further Education" for pioneering the development and deployment of new archaeological technology and techniques. Among the projects included in the honour is the "Stonehenge Hidden Landscapes Project" which was led by the University of Bradford and the Ludwig Boltzmann Institute for Archaeological Prospection and Virtual Archaeology. The project lies within the "Visualising Heritage" key research theme at the University of Bradford. The coveted prize, which honours world-class excellence and achievement, is the highest form of national recognition that UK higher education institutions can achieve.

Careers

In the course of implementing the institute's continuation concept and associated staff transfers, researchers Hannes Schiel and Mario Wallner accepted a permanent position at the LBI ArchPro partner organisation ZAMG. They joined the Archeo Prospections® group at the department for applied geophysics in November 2021.

1.4 Research Programme

The first funding period of the LBI ArchPro 2010-2014 was dominated by the set-up of the institute with a major focus on the development of efficient motorised geophysical prospection systems and respective data acquisition, navigation and processing software, fieldwork logistics for large-scale applications and methodological developments in airborne laser scanning and airborne imaging spectroscopy and the GIS-based mapping and interpretation of the respective data sets from the international case studies defined with the partner organizations. For the second funding period 2017-2024, the research programme was revised and structured with the definition of respective foci (Fig. 4).

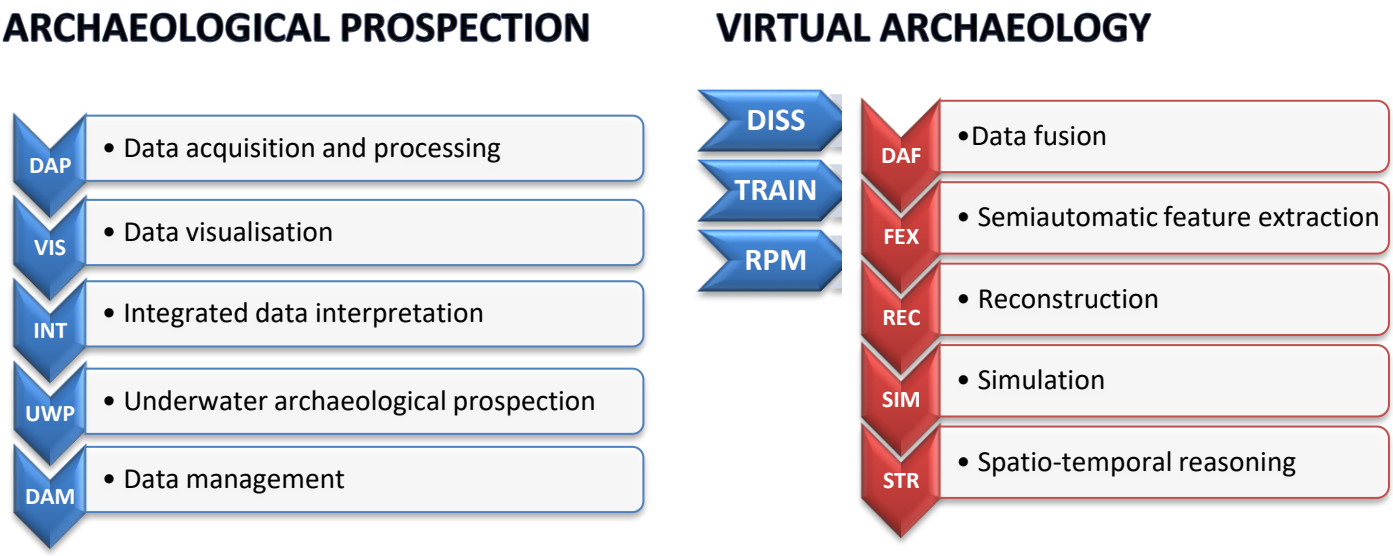

Fig. 4. Research topics within the fields ARCHAEOLOGICAL PROSPECTION and VIRTUAL ARCHAEOLOGY

The overarching subject area dissemination and awareness (DISS) warranties high profile scientific publications and regular outreach to the wider public and important non-academic stakeholders. The subject area training and teaching (TRAIN) comprises the provision of substantial academic teaching and training offered at the University of Vienna, among others, and through participation in summer schools. With the help of strategically chosen case studies the new developments are tested,

advanced, and exemplarily demonstrated. Third party funded research projects offer popular possibilities for students and early-stage researchers to gather hands-on experience through participation in current, exciting archaeological prospection and digital documentation projects.

In the following, the progress made over the course of 2021 is described according to the defined research topics and lateral programme elements.

2 Data acquisition and processing (DAP)

2.1 Geophysics

EU Interreg DTP project "Living Danube Limes »

Short description of project: Geophysical prospection of selected international pilot sites in the framework of the project
Short description of sites: Roman fortifications, settlements and/or necropolises on agriculturally used fields, grasslands and/or partly covered with younger/modern superstructures along the Danube in Slovakia, Hungary, Croatia, Bulgaria, and Romania
Datasets: Magnetics, GPR, IBM
Keywords: EU project, transnational research, Roman heritage along the Danube
Benefits: supporting archaeological research on pilot sites which will serve as role models for the development of sustainable tourism and transnational heritage site management plans, filling research gaps and strengthening hitherto underdeveloped sites in the Eastern Danube Region

Due to the persisting pandemic and concomitant travel restrictions in 2020 and the first half of 2021, geophysical prospection surveys at the selected pilot sites in five partner countries were carried out within in a relatively tight time frame in fall 2021 (see also chapter 12.5).

Iža-Kelemantia and Jarovce (SK)

Geophysical surveys at the Slovakian pilot sites were carried out between 26-27 August 2021 at Iža-Kelemantia and on 11 October 2021, at Jarovce/Roman Road.
The Roman military fortress near Iža was once built as a fortified bridgehead for the crossing of the river Danube and with its masonry enclosure occupies a special position within the Limes fortifications. The fortress was already investigated by large-scale archaeological excavations at the beginning of the 20th century and has lost none of its research interest since then. This year's investigations using GPR were carried out with two different measuring frequencies (500 MHz and 250 MHz) in order to make the best possible use of the potential of this non-destructive prospection method. Within two survey days, the entire inner area of the fortress (3.0 ha) could be documented. The fieldwork in Iža yielded very good results, mainly by confirming the previously excavated features, both in terms of their location and details (Fig.5).

Fig. 5. Above: Overview of the GPR survey with 250 MHz at the Roman fortress Iža. Below: Archaeological interpretative mapping of the GPR surveys.

Jarovce (SK) is located directly on the Slovak-Austrian border, south of Kittsee. Through this municipality, the Roman road runs from Gerulata to Carnuntum. Together with the Slovakian project partners and the lead partner, it was agreed to include sections of the road in the geophysical investigations in Slovakia as part of the project. The route of the Roman road from the state border to the intersection with the D4 motorway was surveyed on the 11th of October 2021 using a motorized fluxgate magnetometer system; around 10 hectares could be measured. Technical issues and the advanced growth stage of the local crop prohibited the continuation of the survey in 2021. The initial results are promising and justify a further investigation south of the motorway in 2022.

Sacidava (RO)

Geophysical surveys in Romania and Bulgaria were conducted within a combined fieldtrip: The geophysical prospection survey in Sacidava was carried out on the 24th and 25th of September 2021. On the first day, surveys were conducted within the Roman fortress of Sacidava (field Aa, 0.95 ha), as well as within the early medieval settlement (field B, 0.66 ha), and the Getic fortress (field C, 0.34 ha), using a motorized fluxgate magnetometer system (Fig. 6). On the second day, parts of the agricultural field south of the Roman fortress were surveyed (field Ab, 1.67 ha), using the same magnetometer system. Altogether, 3.62 ha could be surveyed with magnetometry. The fieldwork yielded rather good results, several strongly magnetic anomalies suggesting graves, straight rectangular building structures and other settlement traces, were observed.

Fig. 6. Motorized magnetic survey at Sacidava.

Vidin – Bononia and Sinagovtsi (BG)

The geophysical prospection survey in Bulgaria was carried out on the 27th (Widin/Bononia) and 28th (Sinagovtsi) of September 2021. On the first day, surveys were conducted at the Roman fortress of Baba Wida (0.4 ha) in Widin, using a motorized ground penetrating radar system. On the second day, several agricultural fields east of Sinagovtsi in the area around recently conducted rescue excavations were surveyed (1.84 ha), using a motorized fluxgate magnetometer system. Thus, altogether, 0.4 ha could be surveyed with GPR and 1.84 ha with magnetometry. The fieldwork in Widin yielded rather good results. In the centre of the western survey field a rectangular building, separated into a larger room to the west and a smaller room to the east, became apparent. The building is partly superimposed by the museum to the west and could thus not be surveyed entirely, however, it

measures at least 12 m x 14 m. The fieldwork at Sinagovtsi yielded less unambiguous results, showing many magnetic dipole anomalies derived from metal objects, several negative magnetic linear anomalies indicate former agricultural use, and many positive magnetic probable pit anomalies with diameters between 0.5 m and 3 m.

Százhalombatta – Matrica (HU)

The geophysical survey in Százhalombatta/Matrica was carried out between the 3-5 November 2021 (Fig. 7). On the first day, GPR surveys were conducted within the Roman vicus. On the second day, one agricultural field to the north around the Roman bath and two further fields in the area around the Roman fortress were surveyed. On the third day, the survey of the most southern field was completed. The survey conditions can be described as rather favourable, with the exception of the heavy rain on the second survey day. All fields were harvested, or free of higher vegetation upon arrival, they thus provided relatively smooth surface conditions. Altogether, 5.24 ha could be surveyed with GPR. The fieldwork at Százhalombatta yielded very good results, including probable Roman houses with adjoining agricultural fields, large pits with diameters between 1.5 m and 3.5 m, and massive Roman walls, pillars, and buildings. With very high probability, some of the structures can be assigned to the phase of the Roman fortress, showing typical ground plans comparable to known Roman building elements (Fig. 8).

Fig. 7. Overview of the surveyed fields at Százhalombatta (HU).

Fig. 8. Left: Overview of the GPR survey in the area of the Roman fortress at Százhalombatta. Right: Archaeological interpretative mapping of the GPR survey.

Kopačevo/Ad Labores (HR)

The geophysical survey at Kopačevo/Ad Labores was carried out between 15-18 November 2021. The primary area of interest – the site of a Roman fortress in the village - could not be investigated as the landowner refused to grant access permission. For this reason, areas of ca. 2.4 hectares in total were examined around the village and north of the small fortress in two days using a motorized ground penetrating radar system.

Battlefield Marchfeld 1278

Short description of the project: Large scale geophysical prospection of an archaeological and historic landscape

Short description of site: Right bank of the river March (Lower Austria) and accompanying mountain ranges

Datasets: Magnetics, aerial photography

Keywords: geomagnetic survey, deserted village, landscape archaeology, large scale geophysics, dissemination

Benefits: landuse in archaeological and historic times, shift of settlements in time, workflow improvements

In 1278 one of the biggest battles of the Middle Ages took place on the right bank of the Morava near Dürnkrut and Jederspeigen. The leader of the winning army Rudolf von Habsburg secured a dominant position for his dynasty in Central Europe for the following 640 years. According to historical sources, over 50.000 people took part in the battle. The geophysical investigations were aimed at exploring the traces such a large-scale battle has left in the ground. This year's campaign focussed on the areas where, according to historical sources, the army camps were located. In

summer 2021, 2.5 km^2 were examined using motorized magnetometer-sytems. The project was also documented by a film team for a TV documentary on the famous battle which aired on national TV (ORF2) in the beginning of 2022.

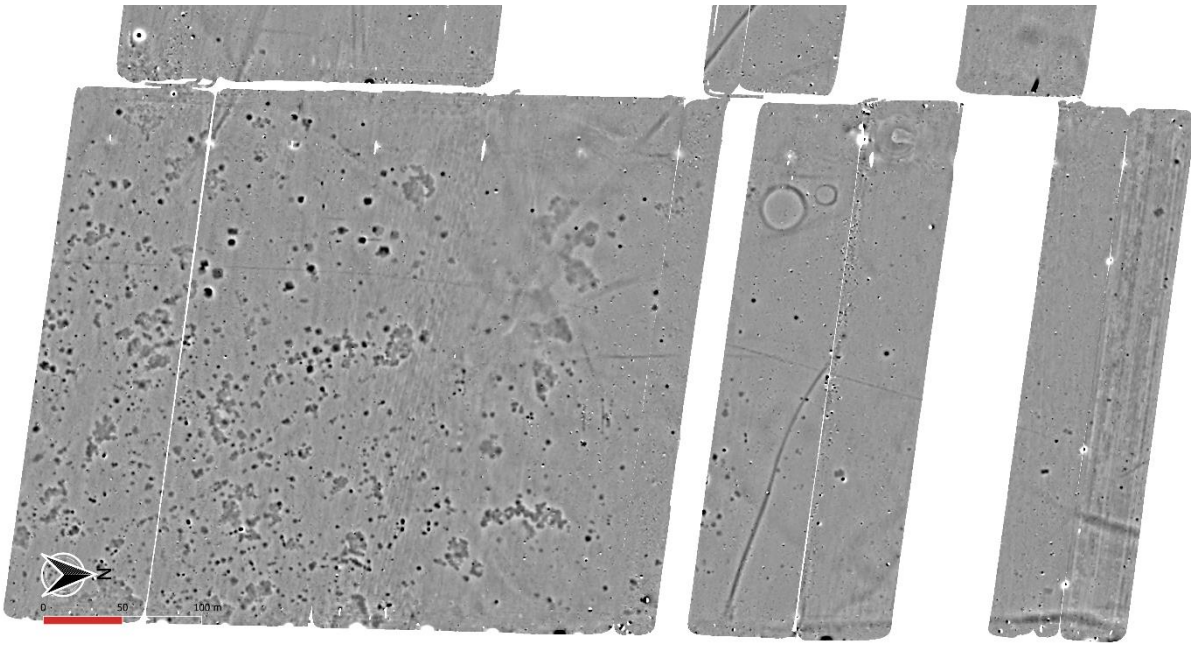

Fig. 9. Settlement zone with features primarily from the Iron Age and the Roman Imperial Age in Waidendorf. The camp of Rudolf von Habsburg is also assumed to be located here.

Rudolf von Habsburg's camp was located south of the battlefield on a ridge that rises up to 20 meters above the plain. An intensively used settlement zone could be identified here, which can be dated to the (early?) Iron Age and the Roman Empire (Fig. 9). At the northern edge of this zone, there are several burial mounds and a circular anomaly that has not yet been definitively assigned. The camp of Ottokar von Böhmen, the leader of the defeated side, is said to have been located in the loop of the March in Sierndorf. A double ditch could be found here, which probably fenced in a medieval deserted village. Another deserted village between Jederspeigen and the March was also partially examined (Fig. 10). The settlement, which is equally marked by two ditches, has been explored in small parts by rescue excavations, the results of which indicate that the settlement was abandoned in connection with the battle. Inside, a parcel subdivision seems to be visible. At least one fortification is connected to the settlement, aerial photos indicate another one in the immediate vicinity. Archaeological features can be found in almost all of the examined areas, some of which are outstanding. Although no features have been identified that can be attributed exclusively to the battle of 1278, the results of the areas prospected so far represent excellent evidence of the potential of geomagnetic prospection on prehistoric and early historical areas for revealing connections between archaeological features and the landscape in which they are embedded. The archaeological interpretation of the prospection data will be completed in 2022.

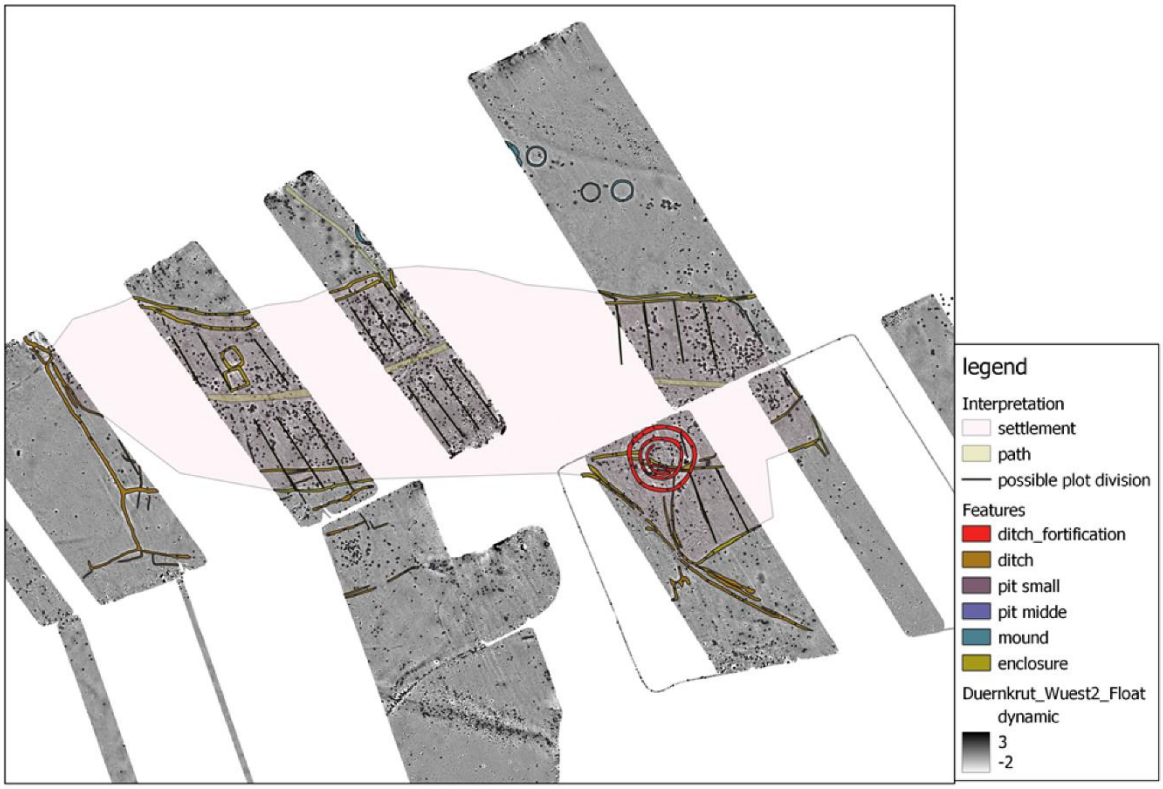

Fig. 10. Medieval deserted area east of Jedenspeigen with a fortification (motte) already prospected, the second is in the field directly north of it.

The medieval town of Corvey, Höxter (Germany)

Short description of the project: Prospection of the medieval deserted village of Corvey
Short description of site: medieval deserted village
Datasets: GPR (SPIDAR)
Keywords: Medieval settlement, UNESCO World Heritage site
Benefits: non-invasive documentation of a World Heritage site, cooperation with partner LWL

In October 2019, first GPR and geomagnetic surveys had been carried out together with the LBI ArchPro partner LWL at the deserted medieval town of Corvey. Geophysical surveys that had been scheduled at Westfalen for 2020 had to be postponed to 2021 due to the COVID pandemic. In 2021, geophysical surveys were continued in the vicinity of the UNESCO World Heritage Site of Corvey. A total area of almost 9 ha could be measured with ground penetrating radar (SPIDAR 500MHz) in November. The surveys concentrated on the farmland in the Weserbogen (Fig. 11), which had not been accessible the year before but had already been covered with magnetometry in 2019. In addition to road surfaces, cellars and wells of the deserted medieval settlement, the GPR-data revealed the remains of a garden design shown on a map from 1798.

Furthermore, the GPR data set of the Marktkirche, which was documented in the 2019 geophysical campaign, was used to test denoising filters for optimal perceptibility of certain features and to investigate the applicability of interactive 3D image segmentation algorithms to GPR data that were integrated into the visualization software (see chapter 3).

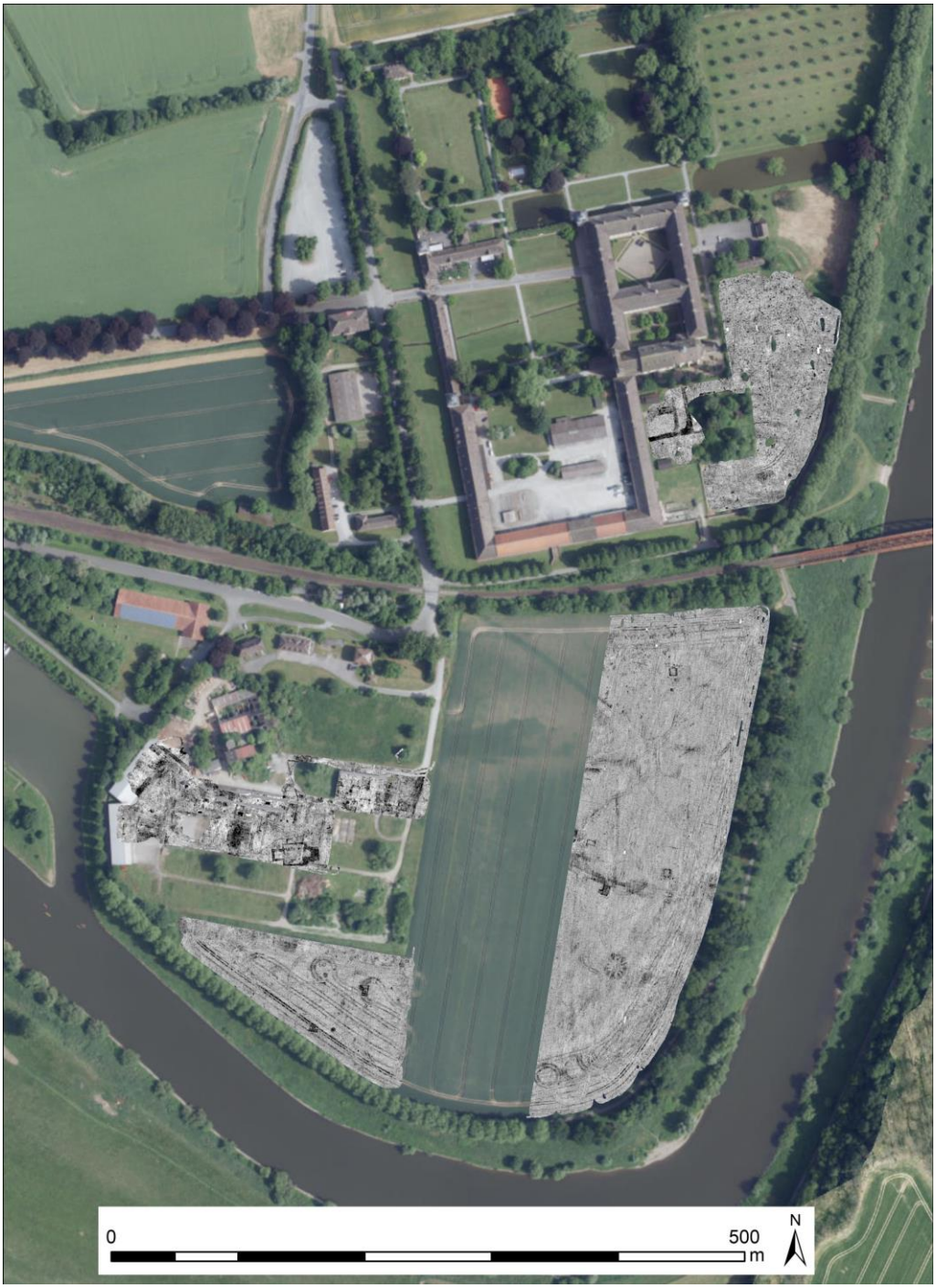

Fig. 11. GPR survey areas at Corvey in 2020.

2.2 Extension of ApSoft 2.0

The individual modules of the software package ApSoft for sophisticated data processing of geophysical prospection data, developed by the LBI ArchPro in cooperation with the partner ZAMG, were improved. ApRadar was further developed to support new components, mainly for new radar antennas, including the Malå GX 450 MHz antenna, the Malå Mira HDR multi-antenna system, Impulse radar systems and new SPIDAR systems, but also for new positioning components, mainly for the new Emlid GPS antenna. Furthermore, a tool to transfer stacked out area data into free positioned area data for Noggin & Malå hand driven systems was developed. ApMag was also adapted to support the new Emlid GPS antennas. Furthermore, new methods were implemented to

remove random sensor noise and a new method to suppress stripe-like patterns in the direction of travel.

2.3 Image-based modelling

Image-based modelling forms the basis of many archaeological documentation workflows and data gathering strategies. Despite its accepted importance to gather archaeological 3D surface data, there is a striking lack of in-depth research about this matter, both from a technical and practical viewpoint. At the LBI ArchPro, both aspects are continuously researched and improved.

Acquisition and processing of UAV-based images into a detailed DSM

The following text is an excerpt from the published paper:

- Filzwieser, R., Ivanišević, V., Verhoeven, G., Gugl, C., Löcker, K., Bugarski, I., Schiel, H., Wallner, M., Trinks, I., Trausmuth, T., Hinterleitner, A., Marković, N., Docter, R., Daim, F., Neubauer, W. 2021. Integrating Geophysical and Photographic Data to Visualize the Quarried Structures of the Roman Town of Bassianae. Remote Sens. 13 (12), 2384. DOI: 10.3390/rs13122384.

Data acquisition

The UAS survey above Bassianae took place from Friday 27th to Sunday 29th of June 2014. Over three days, aerial imagery was acquired during nine UAS sorties. All flights featured the md4-1000, a high-end electrical quad(ro)copter from microdrones GmbH (Fig. 12). The multi-copter was equipped with a 16.1-megapixel Sony NEX-5N camera with a Sigma 30 mm f/2.8 EX DN lens attached.

Fig. 12. The md4-1000 quadcopter with a Sony NEX-5N mounted in a small carbon fibre camera mount on site.

Because the aerial imagery was intended for Image-Based Modelling (IBM) using photogrammetric and computer vision-based approaches, the acquired photographs had to facilitate the Structure from Motion (SfM) and Multi-View Stereo (MVS) algorithms that are at the core of such hybrid 3D modelling pipelines. Second, the airborne data should enable the creation of a raster DSM with a 5 cm cell size (and corresponding orthophoto). This means that image acquisition followed specific rules to ensure that both goals could be met. Before every flight, the Sigma lens was pre-focused on infinity and its focus ring fixed with cellophane tape. In that way, the camera's interior orientation was assumed to remain relatively stable throughout every flight. The camera's shutter was released every two seconds and images were acquired with an f/5.6 aperture in aperture-priority mode. The ISO value and shutter speed were allowed to vary with the illumination conditions, but their respective values neither surpassed ISO 400 nor dropped below 1/1000 s. All photographs were saved as RAW images.

The copter was steered in straight and long parallel lines over the site at a predefined altitude of about 150 m. Given the 30 mm lens and 4.8 µm-detector pitch of the Sony NEX-5N, this altitude yields images with a 2.4 cm Ground-Sampling Distance (GSD), considered suitable for extracting 3D topographic details up to 5 cm (and enabling a DSM raster cell size of 2.4 cm, which is twice as small as needed). The copter continuously moved at about 5 m /s to maximise the area covered by each flight and avoid platform vibrations originating from slowing down and hovering. The slowest shutter speed of 1/1000 s was still fast enough to avoid pixel smear exceeding half a GSD (at 5 m/s, pixel smear is only 1 µm in image space or 5 mm in object space). A handful of long cross lines were flown at a lower altitude in addition to the parallel flights. Both sets of nadir images were complemented by over one hundred oblique images, obtained in three panorama-style acquisitions at different spots of the survey area. These deliberate changes in image scale (intra- and inter-image) and sensor rotation create a more robust camera network geometry and improve the camera self-calibration during the SfM stage.

White circular cardboard plates with a diameter of 25 cm were distributed over the survey area. Their centre coordinates were measured with the JAVAD TRIUMPH-1 rover, resulting in a collection of 96 3D point coordinates that could be used as Ground Control Points (GCPs) to constrain the SfM bundle adjustment. Because the UAS flights took place during the geophysical surveys, it was impossible to position and measure all targets in one run: the GPR instruments would ruin the targets, while the iron nails would interfere with the magnetic sensors. Positioning and topographically surveying these targets took, therefore, place during three consecutive days. Some targets were surveyed twice in this process, which meant that one could compare both coordinate triples.

Fig. 13. During Bassianae's UAS survey, the scene was anything but spatially invariant. (a) shows some of the severe surface changes that occurred due to vegetation clearing. These changes are also observable on the left sides of the photographs in (b), while the grass patterns due to the geophysical survey were less obtrusive (compare the right sides of the images in (b).

Sadly, the scene itself changed during image acquisition. Upon arrival, long vegetation was still partly covering the Bassianae survey area. Because geophysical prospection occurs ideally on fields void of long grass and bushes, the latter were cut (and sometimes also removed) during the survey days, thereby creating a few drastic changes across certain parts of the site (see Figure 13). Towing the geophysical instruments also patterned the grass (Fig. 13b). However, these scenery changes posed only a minor issue during the data processing. In the end, the whole IBM processing pipeline consisted of numerous tests and many workflow iterations. Since this text cannot solely focus on processing these data, the next paragraphs summarise the DSM's creation.

Data processing

After the conversion of the RAW files into 8-bit JPEGs using Adobe Lightroom 5, blurry and documentation-style images were deleted to yield a final set of circa 5100 photographs. All image pixels belonging to persons, cows, cars, and geophysical instrumentation were masked in Agisoft Metashape Professional version 1.7.1. Image areas depicting vegetation changes were left unmasked as masking typically prevented the estimation of these images' exterior orientation. Photos were grouped to compute flight-specific interior camera orientations. After an outlier detection based on a Leave-One-Out Cross-Validation (LOOCV), the coordinates of 93 out of 96 reference points were withheld and used as GCP. The centre of these 93 targets was indicated in every photograph that depicted them, resulting in approximately 3900 Metashape markers. Upon running the SfM algorithm, Metashape was instructed to use maximally 40 000 interest and 4 000 tie points per image; the camera self-calibration solved for three radial (k_1, k_2, k_3) and two decentering lens distortion parameters (p_1, p_2). The coordinates of the 93 GCPs were determined to be 2 cm accurate, whereas indicating these points in the images was quantified with a 3-pixel accuracy. Many tests revealed that these two values provided the best weighting of the control data within the SfM's bundle adjustment. They resulted in the lowest positional inaccuracy (see later) of a DSM with minimal surface artefacts (see also later).

With the interior and exterior camera orientations from the SfM step as input, the MVS step can yield a dense and continuous 3D surface encoding. To that end, Metashape offers two different approaches, both based on the computation of a depth map for each input view. However, rather than a 3D surface, the aim was to create a regularly gridded 2.5D DSM of the *Basssianae* area. 2.5D elevation rasters are, together with triangulated/triangular irregular networks or TINs, the prevalent surface representation schemes used within GIS environments because most GIS software struggles till this very day with large, meshed 3D elevation models. 2.5D height fields and TINs effectively discard half a geometrical dimension when compared to 3D surface encodings. The associated information loss notwithstanding, this dimensional reduction makes 2.5D rasters suited for the fast execution of specific computational methods (such as relief visualizations). Besides, such elevation rasters can often satisfactorily approximate any surface lacking quasi-vertical walls, overhangs, and under-cuttings.

Although Metashape could derive this 2.5D DSM from a dense 3D point cloud or 3D mesh, Figure 14 reveals that a depth maps-based approach – available since version 1.6.0 (build 9617) – offered much cleaner surfaces with fewer artefacts for the Bassianae dataset. In agreement with the initial aim, the cell size for this 2.5D DSM was 5 cm, extracted using aggressive depth map filtering to maximally remove surface noise resulting from changing vegetation. Even though the image set comprised varying GSDs, the final DSM looks very convincing, apart from four zones that feature medium surface artifacting (see Figure 14 for the region with the most noticeable artefacts). These unsolvable artefacts are likely due to erroneous exterior orientation values of the cameras in areas with low image overlap. Luckily, these zones are not coincident with important topographic features and did, as such, not hamper the interpretive mapping of the DSM.

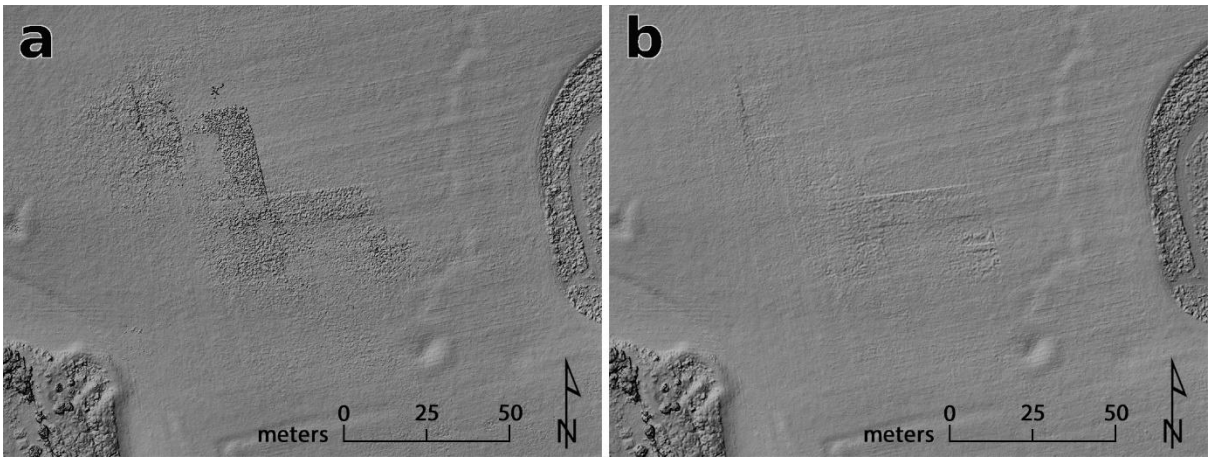

Fig. 14. The 2.5D DSM computed from a meshed dense 3D point cloud (a) and directly from the merged depth maps (b). Notice the reduction of surface artefacts in (b). Both DSMs are rendered as hillshade with 55° solar azimuth and a 35° solar elevation.

With all 93 reference points used as GCP, the DSM and orthophoto's positional accuracy had to be determined via a LOOCV procedure. The mean of all 93 LOOCV residuals yielded: X = 2.3 cm, Y= 2.8 cm, Z = 4.2 cm, XYZ = 6.2 cm. However, it is important to note that this and similar positional accuracy metrics (like a common hold-out validation) often fail to account for DSM artefacts such as those depicted in figure 14. The visualisation of the DSM is reported in the section on Data Visualisation.

Test different ways to compute 2.5 DEMs from imagery

Why 2.5D surface data

In the 2020 annual report, the photographic documentation of a fresco in Vienna's Stephansdom was detailed. These data led to an image-based 3D surface model of the fresco. However, since two-and-a-half dimensional (2.5D) raster surfaces are ideally suited for visualising and analysing sizeable, detailed surfaces, an investigation was started to see how one can achieve the most detailed, noise-free, 2.5D raster surface of this mural painting in Agisoft Metashape.

The following info comes from the published paper:

- Verhoeven, G.J.J., Santner, M., Trinks, I., 2021. From 2D (to 3D) to 2.5D – Not all gridded digital surfaces are created equally. ISPRS Ann. Photogramm. Remote Sens. Spatial Inf. Sci. VIII-M-1-2021, 171–178. DOI: 10.5194/isprs-annals-VIII-M-1-2021-171-2021.

Different roads to a 2.5D raster DSM from 2D images

With the interior and exterior camera orientations from the SfM step as input, the dense image matching executed during the MVS step can yield a discrete or continuous digital surface. Different classes of Multi-View Stereo (MVS) algorithms exist, but Metashape relies on a depth map-based method. Such approaches compute a depth map for each input view and then merge them into a 3D point cloud or a volumetric representation of the scene. Both types of intermediary products can be converted into a 2.5D raster DSM with one or more additional steps. Metashape provides five different ways (Fig. 15) to end up with a gridded DSM from a set of depth maps.

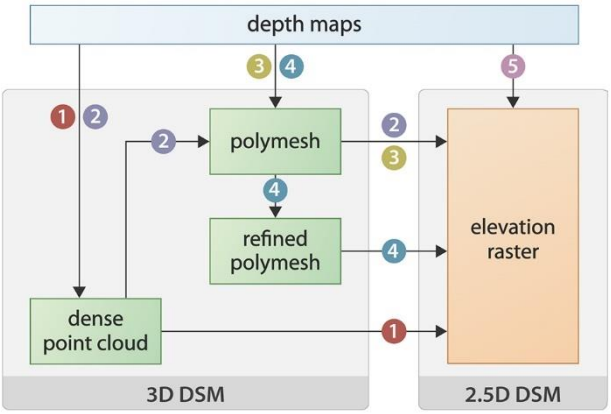

Fig. 15. The five relevant pathways one can follow in Agisoft Metashape Professional 1.7.1 to create a 2.5D raster DSM.

Applying the above approaches yielded five different raster DSMs from the central upper part of the mural painting (Fig. 16). Restricting the comparison to this zone ensured reduced processing times. Because the area includes parts of the relatively flat mural painting, the wavy stone cornice with its undercut (see the outer left inset of figure 16 for its vertical profile), and the small stone ridge below the cornice, these test results are still representative for the complete scene.

A few things can be readily noted when observing the first Region Of Interest (ROI 1). Both the point cloud-based (method 1) and depth maps-based (method 5) DSMs have issues in the most protruding part of the cornice and vertical surfaces of the ridge. DSM 1 contains much noise in both locations, while DSM 5 contains noise and lacks the lower part of the cornice. There are three different surfaces at the level of the cornice undercut (i.e., three different elevation values) that must be 'summarised' in the raster DSM. Metashape prioritises the lowest elevation values so that the protruding part of the cornice gets partly removed in favour of the wall surface behind it. The polymesh-based approaches (methods 2, 3, and 4) convey the front of the stone cornice and the ridge much better. The horizontal, vertical, and slanting surfaces are well-defined and clean; only the raster DSM of the meshed dense point cloud (i.e., method 2) still contains a few noisy locations.

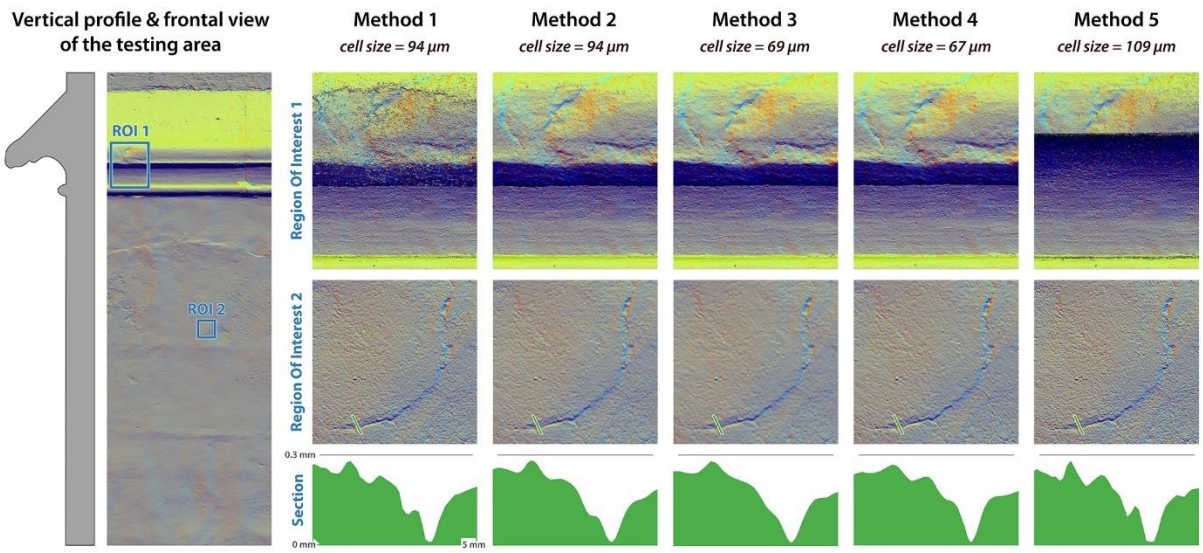

Fig. 16. Comparison of raster DSMs resulting from five different methods. The DSM is visualised using a multiple hillshade technique: a composite of three different hillshades, computed with a 35° elevation for the illumination source and azimuths of 315°, 22.5°, and 90° for the red, green, and blue channels, respectively. The multiple hillshades were linearly histogram stretched to increase contrast. All visualisations are computed with the Relief Visualization Toolbox 2.2.1.

However, a closer look at the raster DSMs in ROI 2 reveals that the three polymesh-based methods encode less spatial detail than the other methods. The fuzziest, least detailed DSM results from method 3. Although it might be surprising that a raster DSM extracted from the depth maps-based polymesh features fewer surface details than a raster DSM from a triangulated dense point cloud (method 2), these results are in line with the assessment of polymesh generation methods reported in other recent papers. Moreover, Metashape estimated a 69 µm raster cell size for method 3, about 30 % smaller than the other methods. This finer grid only increased the file size, not the amount of digital surface detail.

The latter is sometimes slightly increased when deriving the raster DSM from the refined polymesh (i.e. method 4). Metashape's photoconsistent refinement should iteratively recover additional surface details on a polymesh. However, the results of the mural painting show that this processing step is not effortless and leads to variable results. First, refining a polymesh based on the total pixel count (i.e. "Quality" setting "Ultra high") was not possible in Metashape 1.7.1, so the results in this paper were generated with version 1.7.2 (build 12070).

Second, polymesh refinement is highly time and video memory (i.e. VRAM) intensive. The user also must balance the iteration count (more iterations might recover more surface detail at the expense of processing time) with a "smoothness" parameter (less smoothing might recover more surface detail at the expense of noise). Here, all refinements used five iterations and a 0.5 smoothness factor.

Third, refinement results largely depend on the number of input images. The cleaner and more detailed surface geometry visible in Figure 16 (method 4, ROI 2 and section) was only achievable after deactivating 80 % of the images. Upon refinement with all images, barely any additional surface detail could be recovered. Finally, including slanted views in the polymesh refinement often increases the surface noise, which is likely related to the increased blur circles of the objects points. Overall, polymesh refinement can yield cleaner raster DSMs with improved surface detail compared to other polymesh-based rasterisations. However, the issues mentioned above prevent it from being a no-brainer. In addition, methods 1 and 5 still outperform method 4 in terms of derived surface details.

Greater-than-life size reproduction of painting

Painting 111-1-10-65, hanging in the Spanish Riding School in Vienna, had to be digitised for a greater-than-life size reproduction in the Piber exhibition. This was accomplished with a dense network of images (see the left side of Figure 17), which were afterwards processed in an image-based modelling pipeline to enable the creation of a correctly-scaled true orthophotograph (see Figure 17 on the right).

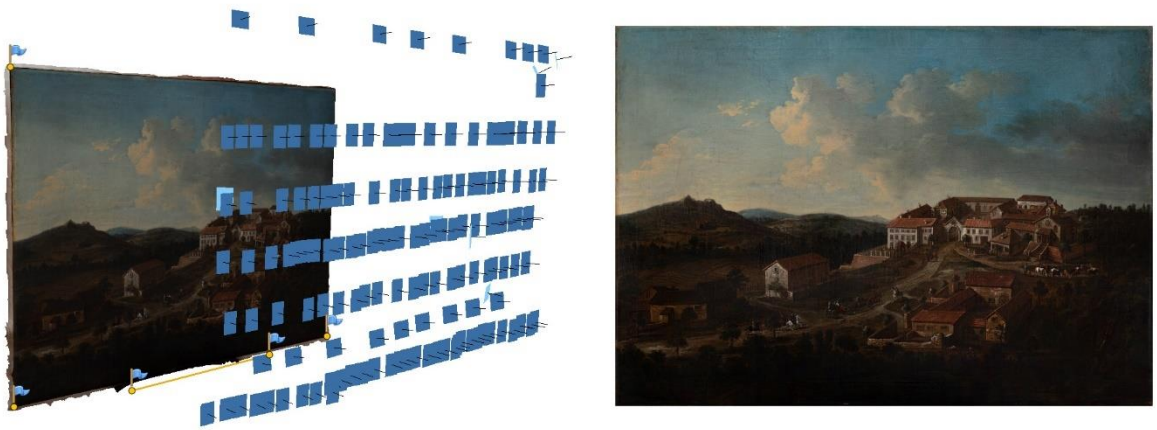

Fig. 17. Orthophoto creation of a painting in the Spanish Riding School in Vienna.

2.4 Terrestrial and airborne laser scanning

3D-surface recording for archaeological purposes always demands a specific mixture of ALS, TLS and IBM techniques (see also chapter 2.3). The choice depends on the location, type and size of the object of interest and the environmental setting, i.e., the vegetation cover, weather, and light conditions. A respective survey is even more challenging, when indoors and outdoors recordings are combined. To obey precision and accuracy a geodetic survey or the application of respective techniques (GNSS) is mandatory.

In 2020 an UAV operated airborne Laserscanning system from RIEGL LMS was introduced to the LBI ArchPro equipment. It consists of a RiCOPTER C20 UAV carrying a VUX SYS Laserscanner combined with two SONY Alpha cameras for RGB data collection. A survey team usually consists of a pilot and an operator responsible for flight path planning and data acquisition.

The Ricopter system consists of three sets of batteries. With each set it is possible to cover an area of 1 to 10 h, depending on flight speed and resolution. The data collection time is limited to 4 to 6 minutes depending on the air temperature. Survey time in winter must be reduced by up to 30 % due to cold weather conditions. Without recharging the batteries only 3 flights are possible per day. Additionally, the pilot´s attention decreases with every flight. Under good conditions (calm weather, no stress, good performance of system) the maximum amount of three flights could be exceeded. In any case the presence of a second pilot is recommended. Keeping in mind that recharging the batteries takes about 1 hour, six flights per day (under excellent conditions) are possible. This results in the maximum coverage of 50 h per day.

A focus of the LBI ArchPro's research programme is set on the evaluation and testing of different approaches and settings of the applied instrumentation optimized for a specific situation. Especially UAV based ALS demands accurate planning in advance including flight plans, survey plans, system parameters (settings of the scanner, flight height, flight speed) and constant monitoring the weather conditions. It turns out that the effective days for 3D data collection are often reduced to an unexpected minimum due to bad weather conditions and seasonal changes of vegetation cover. All these mentioned aspects have been tested at various sites during 2021. In the following theses sites are listed and described regarding archaeological reasoning and methodological testing.

Spanish Riding School and Federal Stud at Piber

With the Leica BLK 360 and Faro Freestyle scanners (both property of partner 7reasons), several artefacts (horse models – see Figure 18, horse tack and carriages) have been scanned in the Lipizzaner Stud Farm in Piber and the Spanish Riding School in Vienna. All resulting 3D point clouds were delivered to partner 7reasons, which used a few of them to generate content for the Piber exhibition (see chapter 10.3).

Fig. 18. Scanning with the Leica BLK 360 in the Spanish Riding School in Vienna.

In cooperation with the LBI Archpro partner Spanische Hofreitschule the ALS survey of the stud in Piber was finalized in May and June 2021. Both areas – namely Stubalm and Afling – demand specific preparation as they are in high altitude (1000 m ASL and 1600 m ASL). During one flight the altitude above ground level (AGL) varied between 25 m and 120 m. This has not only impact on the pilot´s flight strategy – in such areas the pilot´s awareness, concentration and fitness are crucial - but also on the quality of the gathered data. The ground resolution of the data varies according to flight height. The settings of the system are usually optimized for an average flight height of 60 m AGL. Nevertheless, the quality of the gathered data proofed to be sufficient as the object of interest had been mainly grassland without vegetation cover such as trees and bush. An average point density of 400 to 600 points per m^2 and after filtering was achieved.

St. Anna in der Wüste

Since the beginning of the LBI ArchPro St. Anna has been an important case study where ALS and TLS were tested and evaluated constantly. An area surrounding the so called “Meierhof” has been chosen to be monitored throughout various environmental settings in different seasons (Fig. 19). So far, the dataset consists of three flights undertaken in late autumn (no vegetation cover), summer (maximum vegetation cover) and springtime (starting vegetation cover).

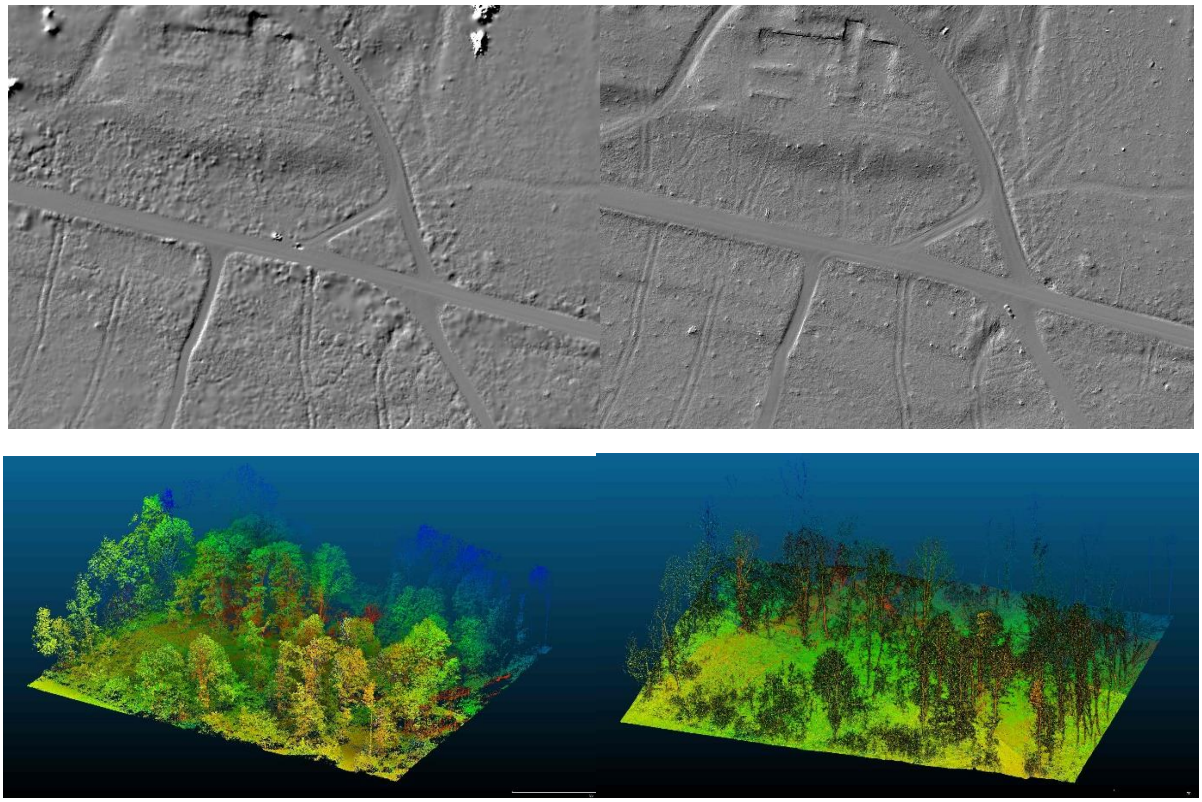

Fig. 19. Situation in May (left) and December (right) at the Meierhof in St.Anna (M.Doneus).

A further focus was set on the recording of walls covered by vegetation (common ivy, hedera helix). The plan of recording the ruin of Scharfeneck was resigned, because no secure flight strategy could be worked out. Instead of the ruin the sites of Weissenburg and Burg Marsbach were chosen to test recording strategies and filtering techniques. Both sites were recorded in spring 2022.

Deserted villages

When ALS data became available in Austria for the wide public many deserted villages have been detected in forested areas north of Ernstbrunn in Lower Austria. Within the research program of the LBI ArchPro a proposal is planned to get further funding for the examination of theses and similar sites in Lower Austria. Among these sites a few were chosen to examine limits of UAV based ALS and to optimize instrumental settings. Different vegetational situations (dense young conifer forest, deciduous trees, light pine tree forest and clearings) have been recorded at different flight speed and scanning frequency (Fig. 20). It is expected that decrease of scanning frequency increases the penetration capability of the laser beam. From these analysis best practice rules for instrument settings in respect to a given vegetational setting will be derived.

A further test was done when the ground was covered partly with snow. Although the VUX SYS is not recommended to be used when snow cover is present, the data quality, when only patches of snow are noticeable, is satisfying (Fig. 21).

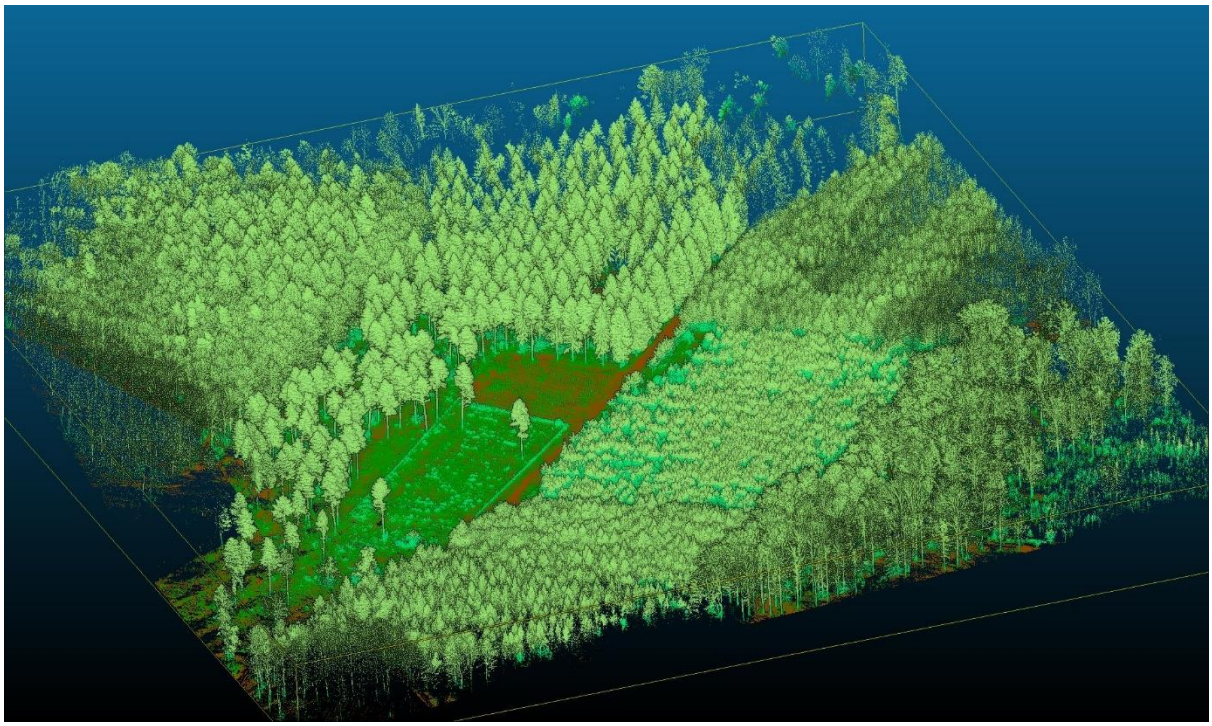

Fig. 20. The test area without vegetation filter. Different classes of vegetation (low, high, dense, conifer trees, deciduous trees) can be observed.

Fig. 21. The testing area after filtering. The structure of the deserted village becomes visible. Smaller snow patches seem to not influence the data quality.

3 Data visualisation (VIS)

Comprehensive data visualisation is crucial for the perception of relevant archaeological information in multi-modal archaeological prospection data sets and therefore of utmost importance for high quality archaeological interpretation of prospection data. Furthermore, illustrative visualisations based on measured data support the dissemination of the results in easily understandable way without sacrificing traceability. A special focus is placed on GIS-based visualisation of prospection data, and integrated visualisation of heterogeneous 3D data like GPR volumes, virtual models, and point clouds.

3.1 Fused relief visualisation

Bassianae Digital Surface Model

In the Data Acquisition and Processing, the generation of the 2.5D Bassianae DSM was detailed. A major advantage of the 2.5D raster DSM is that it enables the fast computation of visualisations that can clearly reveal topographic features. Regarding an overall understanding of the town, with its fortifications, road network and separate insulae, the DSM-orthophotograph blend could probably be considered the most informative source (Fig.). It was created by a "hard light" image fusion of the UAS imagery-based orthophoto with a relief rendering, the latter being the result of a "hard light" image fusion between a multidirectional hillshade (35° solar elevation, vertical exaggeration factor of 3) and local dominance visualisation ([min, max] kernel radii = [20, 40] raster cells) of the DSM. Opacity levels and global contrast levels were tuned for each intermediary fused result to achieve optimum clarity of the topographic features.

Fig. 22. Visualisation of present-day Bassianae *using a DSM-orthophotograph blend.*

3.2 3D data visualisation

Revealing images generated by visualization tailored to the nature of the datasets at hand are a key requirement for optimally exploiting archaeological prospection data. Their interpretation requires both, imagination, and a broad domain understanding. Since most archaeological structures of archaeological interest are three-dimensional, as is the way human observers understand them, it is worthwhile to investigate the possibilities of 3D visualisation with the goal to increase interpretation quality and efficiency. 3D volume visualisation of GPR data generally improves the visual depiction of the archaeological 3D structures, in particular the perception of their 3D shapes, over browsing through stacks of individual 2D image in a GIS system.

Therefore, we continued our research activities towards innovative 3D visualisation techniques for 3D GPR volumes, also supporting the integration of the entire spectrum of data within the scope of prospecting and excavations, which includes 3D point clouds, 3D models from image-based modelling or virtual reconstructions, and 2D images.

The developed visualisation algorithm also supports the flexible conjoint visualisation of multiple GPR datasets with local control over the visualisation parameters, which allows to combine the original datasets and filtered versions from semiautomatic feature extraction. Interpretation models and 3D models from excavations or virtual reconstruction can be included for comparison with prospection data and illustration. Altogether, this leads to unparalleled possibilities for the documentation, analysis, and dissemination of archaeological data.

In 2021 the visualization techniques were developed further with the goal to increase the performance and stability for an initial release of the software. In this course, much importance was attached to the user interface, which was completely revised regarding simpler usability and faster implementation of certain visualization effects, such as changing the spatial arrangement of multiple versions of a GPR dataset in 3D space, the visual portions of the respective datasets, and the rendering type as shown in Figure 23. This is achieved using new controls to change 3D properties such as the 3D location and orientation of a dataset as well as 3D interaction techniques.

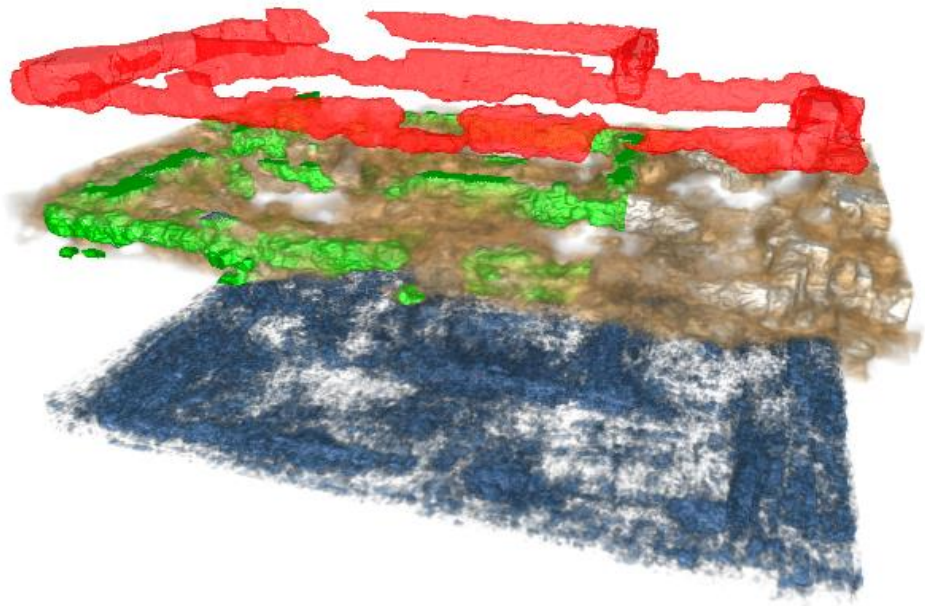

Fig. 23. Illustration showing the showing various possibilities to visualize 3D GPR data, including different version of the dataset (blue: unfiltered, brown&white: filtered, red: segmentation), rendering techniques (blue, brown&white: direct

volume rendering, green, red: iso-surface rendering), visualization domain control, and the possibility to place the respective datasets in 3D space.

Previous visualisations like the ones of the Roman forum of Carnuntum were enhanced and complemented with more dataset and including new visualization techniques as shown in Figure 24, where enhanced local visualization techniques, automated dynamic label placement and 2D GPR profiles were included.

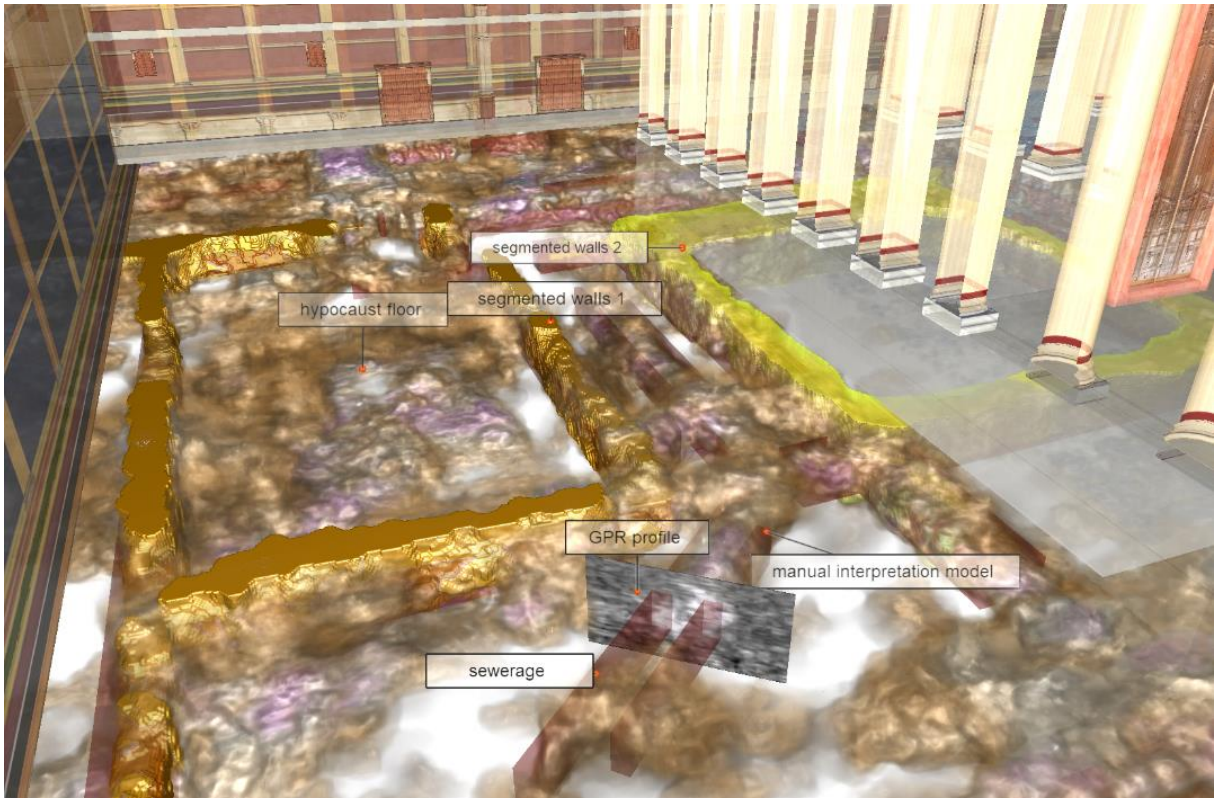

Fig. 24. Visualization of the Roman forum of Carnuntum showing filtered GPR data, a manually elaborated interpretation of wall and sewerage (red), segmentations of the walls of two buildings (orange, yellow) and a virtual model of the forum. The latter was cut away using extended domain control techniques developed in 2021, to avoid occlusion of the orange walls as well as the hypocaust structures. Furthermore, automatically placed annotations of the most important structures are included, as well as 2D GPR profile depicting the cavity inside the sewer.

Hybrid 2D and 3D viewer

The possibility to include arbitrarily oriented an 2D profiles is a useful side effect of the effort towards 3D dataset visualization and exploration using both, 2D and 3D visualization and interaction techniques. Therefore, the existing 3D viewer was supplemented by a 2D viewer providing three orthogonal slice views in analogy to medial diagnostic software for CT and MRI datasets. The 2D views are linked to the 3D views, thereby combining the advantages of both worlds, the immediate perceptibility of shapes in 3D, and the voxel-precise interaction 2D (Fig. 25).

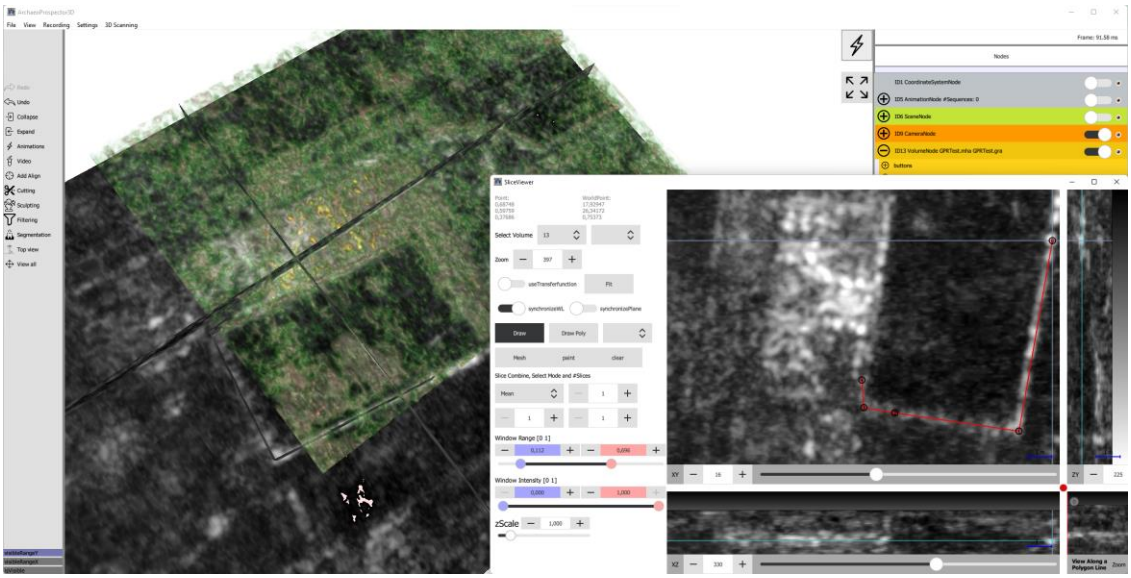

Fig. 25. Linked 2D and 3D viewer supports the exploration and interaction with the data in both worlds, 2D and 3D. While 3D supports the perception of 3D shapes, 2D is ideally suited to inspect detail, and high precision interaction tasks, like the specification of GPR profiles shown in the 3D view, and interaction in the context of semi-automated feature extraction.

Animation editor

Dissemination of knowledge gained based on 3D data visualization of then requires more that static images. Therefore, an animation editor based on so-called key frames was developed. This functionality allows to store all visualization parameters including the position of the virtual camera, as well as the visible datasets at any time, thereby defining a key frame. In the animation editor, these key-frames can be placed on a timeline and modified if required. Furthermore, interpolation methods between the key frames can be defined for the following video support.

Altogether, the set of features is based on common animation and video editing software, and thus enables the rapid generation of video sequences by animating the transitions between key frames.

4 Integrated data interpretation (INT)

The comprehensive interpretation of archaeological and historical landscapes is a main objective of the research and development work. Therefore, a dedicated research topic is devoted to the advancement of integrated data interpretation methods and techniques and to the training of the LBI ArchPro team, especially young researchers and students, and partner staff in these research topics.

4.1 Bassianae

Short description of the project: Large-scale geophysical and aerial prospection of a Roman settlement
Short description of site: Roman settlement in the Vojvodina region of present-day Serbia, positioned along the road between the larger towns of Sirmium and Singidunum in the hinterland of the Danube limes
Datasets: Magnetics, GPR, aerial photography
Keywords: Roman town, landscape archaeology, large-scale geophysics, UAS, image-based modelling, dissemination, multi-methodological approach
Benefits: complementary archaeological prospection approach, collaboration with international research institutions

In 2014, the LBI ArchPro conducted a large scale prospection survey in collaboration with the Institute of Archaeology Belgrade and the Serbian Academy of Science and Arts at the Roman town

of Bassianae (Serbia). All of the town's intramural (and some extramural) areas were surveyed using aerial photography, ground-penetrating radar, and magnetometry to analyze the site's topography and to map remaining buried structures.

With focus on a dedicated publication in the open-access journal "Remote sensing", comprehensive processing, integrative analysis, and interpretation of the previously acquired data sets was carried out in 2021 (see also chapters 2.3 and 3.1). The goal was to further the archaeological status quo which was based on excavation results and aerial photographs from the late 19th and early 20th century. While the UAS-based aerial photographs led to the creation of a very insightful digital surface model, the geophysical surveys were seriously hampered by the in parts very uneven topography with deep trenches.

After combining all survey results, extensive and revealing information on the layout and urban infrastructure of Bassianae could be gained (Fig. 26). The integrated interpretation of all prospection data resulted in an idealized interpretative map that not only considers all results and structures observed in the different survey data, but also tries to fill some of the many remaining voids. Thus, the combined interpretation provided considerably more information than that of any individual dataset, clearly demonstrating the advantages of an integrative, multi-methodological archaeological prospection approach.

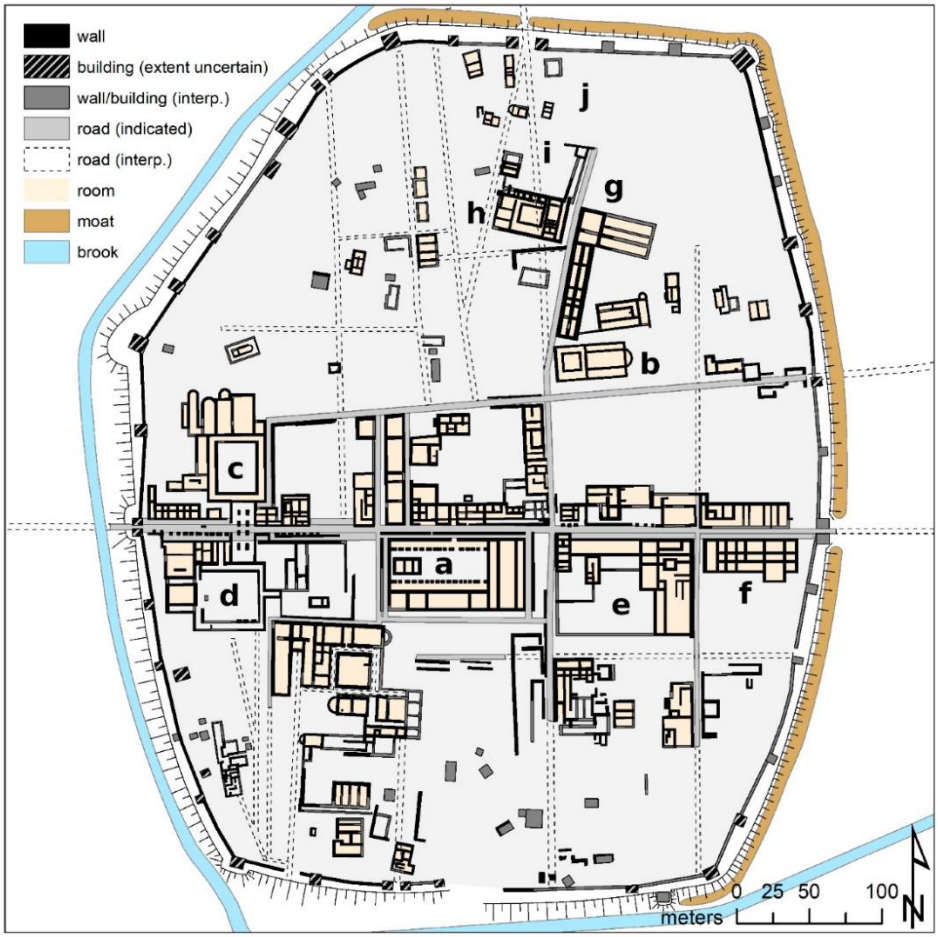

Fig. 26. Idealized interpretative map of the Roman town of Bassianae based on the integrated archaeological interpretation of all three data sets (MAG, GPR, UAS).

- Filzwieser, R., Ivanišević, V., Verhoeven, G., Gugl, C., Löcker, K., Bugarski, I., Schiel, H., Wallner, M., Trinks, I., Trausmuth, T., Hinterleitner, A., Marković, N., Docter, R., Daim, F., Neubauer, W.

2021. Integrating Geophysical and Photographic Data to Visualize the Quarried Structures of the Roman Town of Bassianae. Remote Sens. 13 (12), 2384. DOI: 10.3390/rs13122384.

5 Data Management (DAM)

ArchPro data are distributed over 5 major locations (Fig. 27): Langenzersdorf (LE), ZAMG, the Vienna Institute for Archaeological Science (VIAS) located at the Institute for Prehistory and Medieval Archaeology (IPMA) of Vienna University, a new site in Tieschen, Styria, and the centralized server room of Vienna University's IT department (ZID).

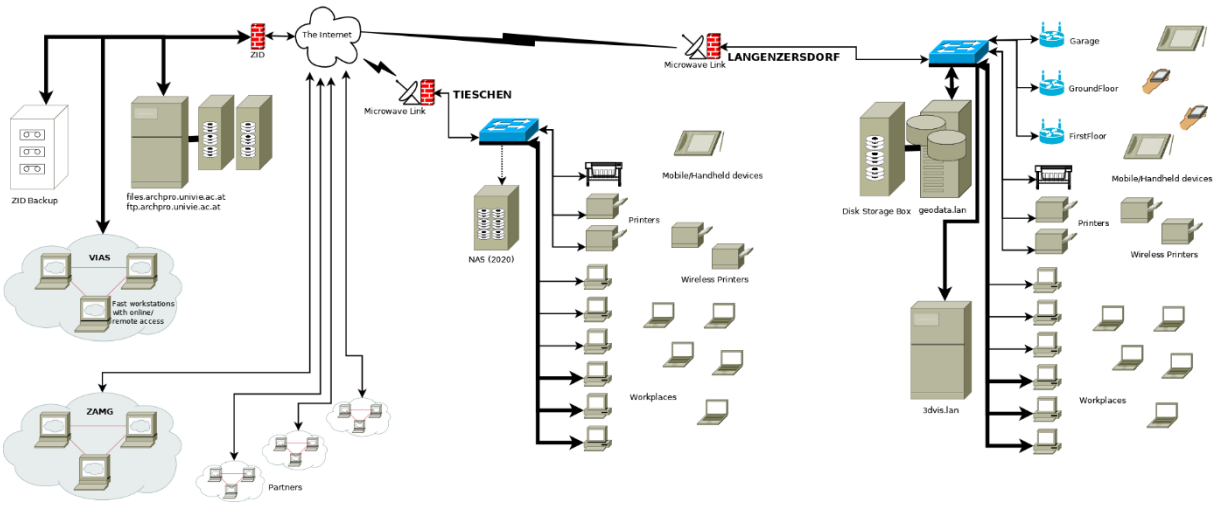

Fig. 27. Distribution of ArchPro data over five locations.

The main file server (with 2 names, {files|ftp}.archpro.univie.ac.at) is located in the Computing Centre of Vienna University, acts mainly as data archive, and is backed up by the IT service department (ZID) of Vienna University. After a major repair in 2018, the operating system was updated from the obsolete Debian 7 to Debian 9 and, early in 2020, to Debian 10. Data archival upload from LE, ZAMG, VIAS, partners, and exchange with partners is performed via SFPT only. Collaborators working at the VIAS, or more generally, inside the VPN of Vienna University, can additionally access this server inside the department's network e.g., as Windows network drive. The server also runs license servers for a few software applications, an SVN repository for software code, and the webserver for HMC+.

LBI ArchPro's main site in Langenzersdorf (LE) was connected only via 4G mobile data service by 3/Hutchinson. In late 2020 a dedicated high-speed radio link was established which together with a VPN allows direct connection from the outside. A second server (named geodata.lan while LE infrastructure has no DNS domain name) had been installed in LE in 2018. This acts as centralized local network file storage for everyday work done in LE and meanwhile via remote desktop connections in the VPN, and could also run geodata services (ArcGIS server, …).

In 2021 the local network infrastructure in LE was improved by replacing the central switch and cabling to ensure 1Gbit/s connectivity for all PCs. The VPN connectivity established in 2020 is now routinely used to access PCs and servers from the home office or remote locations in field work. Fresh measurement data from prospection sites can be directly transferred for processing and analysis at the main site.

Two new powerful PC workstations have been set up in LE for VUX and TLS data processing. These can be reached via VPN (Remote Desktop) so that members can access them also from home office. They are connected to the file server (geodata.lan) via 10GB/s network for even faster data transfer.

The new high-speed data link now allows to store new project data primarily on this server. A nightly backup routine (rsync) sends new data to the Arsenal server where they are mirrored in a new second disk box before being backed up by the ZID tape archive.

A second server had been brought to LE earlier from the LBI for Clinical-Forensic Imaging. On this server virtual machines were set up for various purposes ranging from licence server functionality to a cloud solution based on NextCloud enabling internal document sharing, and versioning remote collaboration.

The network infrastructure at the fourth site, the research center in Tieschen/Styria was planned and implemented from the ground up, so that GBit-Lan is now available in the office and lecture rooms. In addition, WLAN coverage was ensured throughout the entire building. The Tieschen site is seamlessly connected to the main site via a permanent VPN connection using a directional radio broadband internet connection (120 Mbit/s). Researchers in Tieschen may transparently access the servers in Langenzersdorf and vice versa.

To enable rapid and uncomplicated transmission of prospecting data and data collected during excavations, a mobile IT infrastructure setup was developed. This consists of a mobile router for broadband Internet access, a network switch to connect PCs, a long-range access point for WLAN coverage at excavation sites, a NAS with 20 TB storage capacity for on-site processing and archiving of data, and a refurbished uninterruptible power supply, compensating voltage fluctuations of the power generator to ensure safe operation of electronic equipment, all housed in a mobile server rack. Using this rack, an efficient and secure IT infrastructure can be set up quickly at practically any location, from which all resources such as servers and workstations can be transparently accessed and used. It saw its first service in Tieschen in summer of 2021.

Management of the local workstation and laptop PCs are in principle in the responsibility of the respective users. This includes localized and personal backup solutions to external hard disks. Occasional technical advice is given by the IT researchers.

6 Data fusion (DF)

6.1 TAIFU

Over the past five years, much new functionality and many fusion methods have been added to TAIFU (shorthand for the LBI ArchPro's Toolbox for Archaeological Image Fusion). In 2021, TAIFU was not extended anymore as it seems to go unused. This is based on two observations.

1) During an LBI ArchPro visualisation workshop in June 2021, several people expressed their interest in TAIFU. Soon after, TAIFU was compiled with the latest MATLAB release: https://www.dropbox.com/sh/kb361spytg8rdte/AAARyr_ty9FMDws1Wsyenf4Va?dl=1. This release was sent out to every workshop participant with a short manual and request for comments on changes|additions|corrections to TAIFU. However, no further news on the use of TAIFU was received.
2) In 2019, all embedded fusion algorithms were applied to five different test datasets to understand these algorithms' effectiveness for specific geophysical input data. Sadly, till today, nobody has evaluated even a part of this enormous amount of fusion results.

Besides the visualisation of the *Bassianae* DSM (see the Data Visualisation section), the only use of TAIFU in 2021 was related to the InfoSys project, albeit with underwhelming results. All approaches were tested on the GPR, EMI and magnetic data captured within the InfoSys project. In the end, almost no fusion approach was worthwhile (for two examples, consider Fig. 28 and Fig. 29).

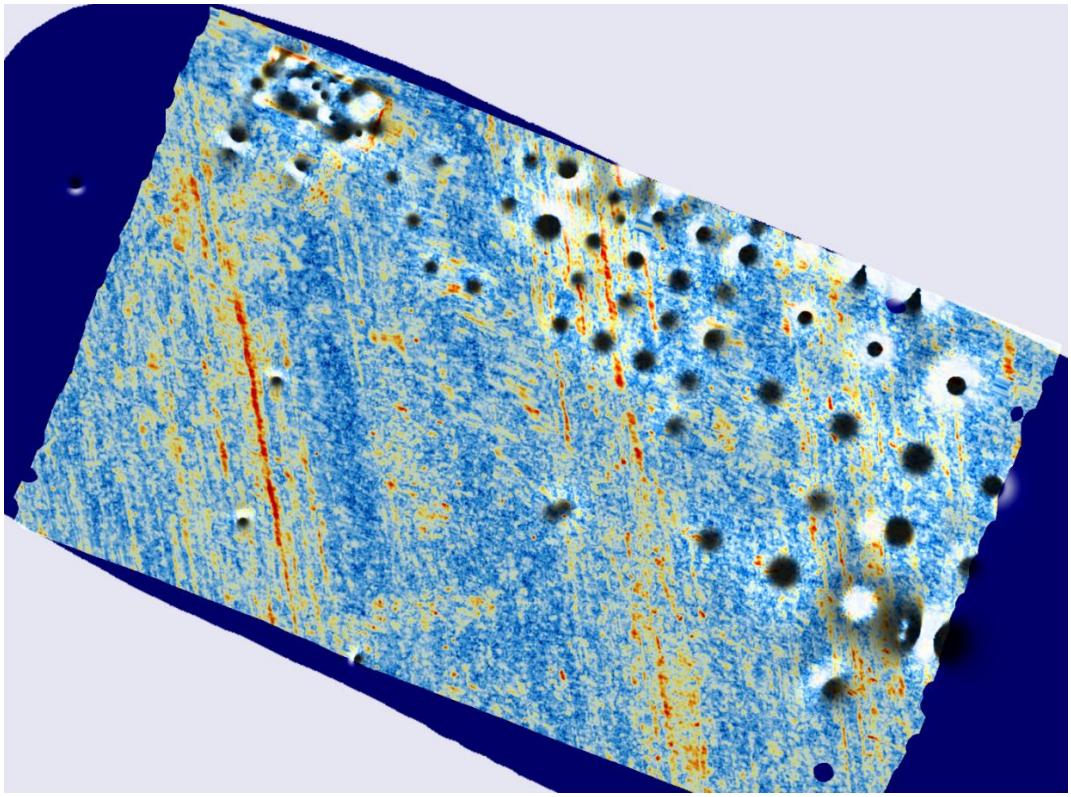

Fig. 28. A2mig_020-025_and_Mag_Sensor50cm_IronAnomalies_20cm_m15p15_sigmoid_FUSED_(hard light).

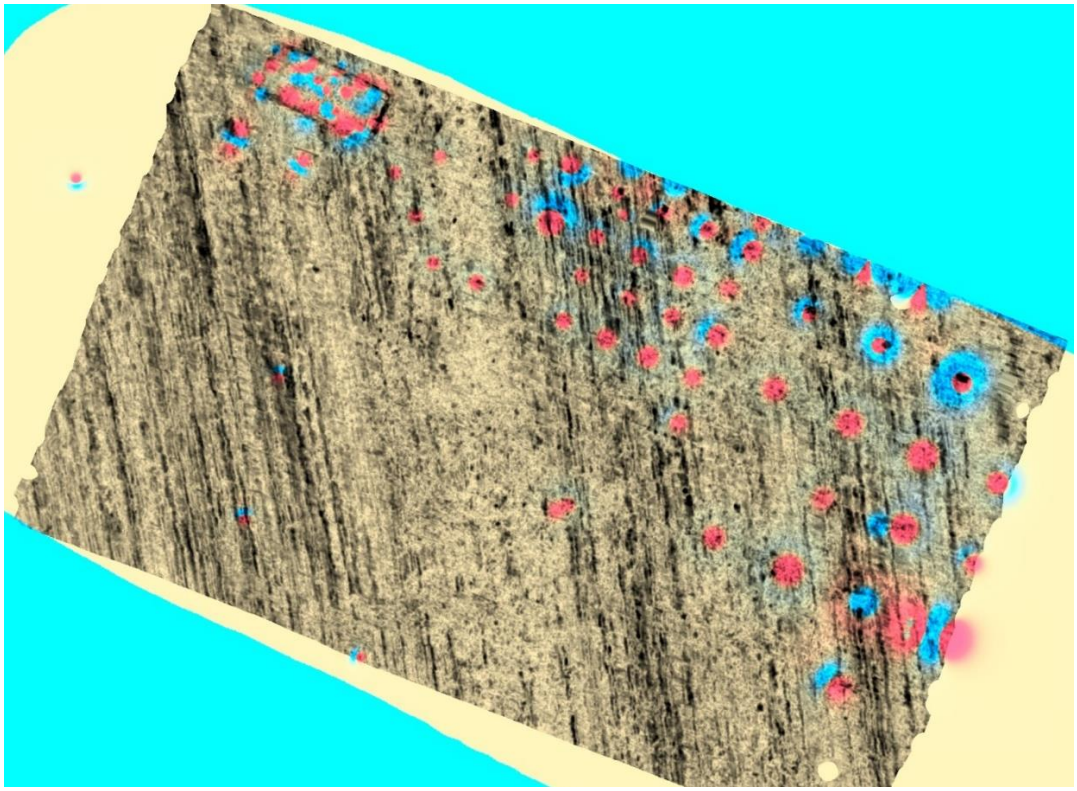

Fig. 29. Mag_Sensor50cm_IronAnomalies_20cm_m15p15_sigmoid_and_A2mig_035-040_FUSED_(pansharpening2).

7 Semiautomatic feature extraction (FEX)

The use of GPR and other prospection modalities have proven to be highly beneficial in archaeology. However, the data as recorded is often not ideally suited for archaeological tasks, most notably interpretation. Firstly, this requires visualisation techniques supporting the discovery and assessment of relevant structures, which can already be hard to archive. Moreover, the interpretation of larger sites or landscapes require a certain degree of automations to be able to accommodate the vast amounts of data.

GPR can capture subsurface information at geometrical resolution on the order of centimetres. The resulting images exposing every single stone appear noisy often prohibiting visualisation depicting archaeologically relevant structures as well as further automated feature extraction.

7.1 Denoising Filters

Filters suppressing small structures and noise while emphasizing larger structures, ideally those of archaeological interest like foundation walls, ditches or postholes have been developed. In 2021 they have been integrated into the visualization software GUI.

Together with the possibility to show two versions of a dataset side by sides and the efficient implementations of the filtering algorithms on the GPU, this enables interactive parameter tuning towards optimal perceptibility of certain features, as shown in Figure 30.

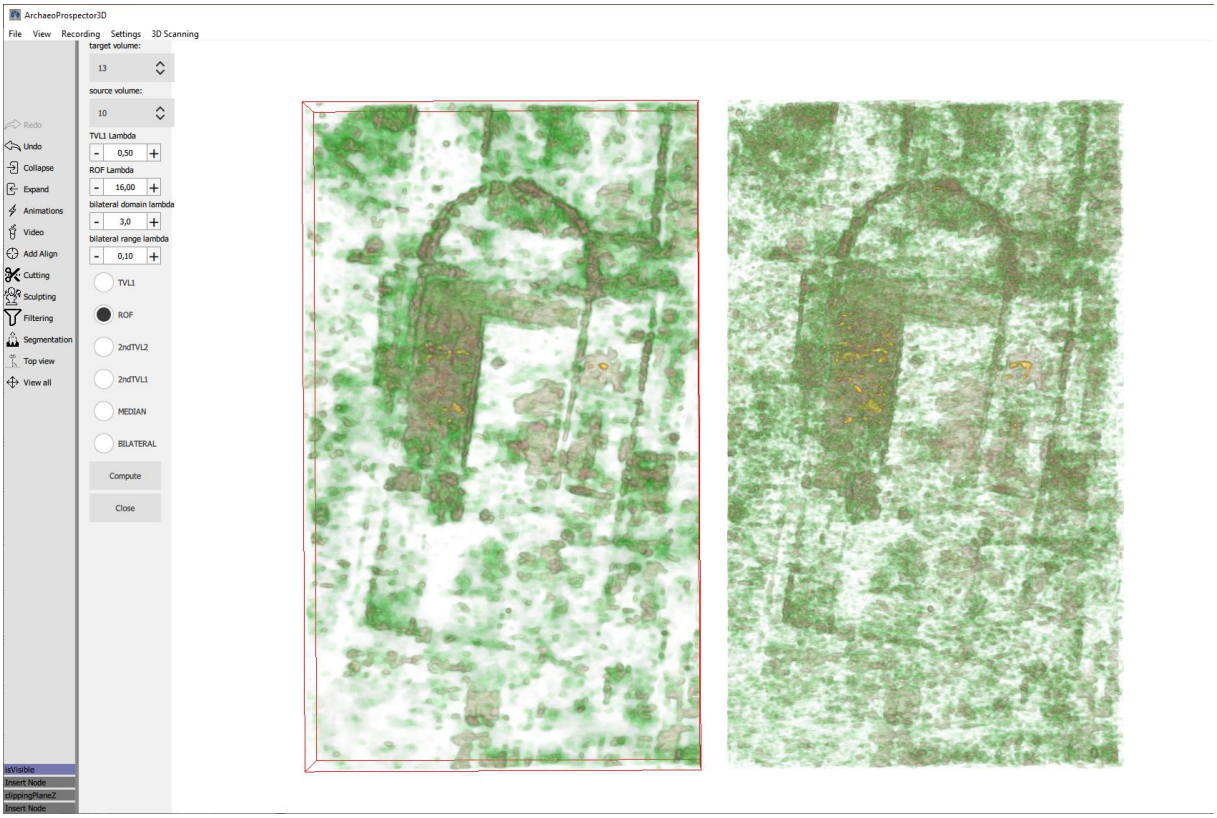

Fig. 30. Side by side visualization of two versions of the Corvey GPR dataset containing the remains of a church. The filtered version on the left may be directly recomputed from within the visualization software using a different algorithm or parameter set.

7.2 Segmentation

In addition to filtering techniques the applicability, of 3D image segmentation algorithms to GPR data has been further investigated. In contrast to filters, segmentation techniques support the explicit extraction of a particular structure in the dataset. Due to the in contrast to medical image processing diverse and unknown shapes of potential interest, the focus was put on interactive techniques.

In 2021 the segmentation functionality was enhanced by including numerous interactive segmentation algorithms. Furthermore, segmentation functionality integrated into the visualisation software, which now supports the whole processing range from the measured dataset, over the computation of filtered versions, to segmentation, where individual dataset features can be explicitly extracted and visualised as shown in Figure 31. This can be exploited to implement a novel type of interpretative process.

Fig. 31. Visualisation of original GPR dataset, filtered version (right) with enhanced floorplan perceptibility (middle), and initial segmentation result (left) obtained using the integrated segmentation tools.

The results of interactive segmentation strongly depend on the quality of the underlying dataset and the filters used to enhance it. For cases where segmentation algorithms fail, dataset editing tools were developed, to remove unwanted geological structures or to manually separate or connect archaeological structures prior to segmentation (Fig. 32).

Fig. 32. Interactive 3D dataset editing tools support direct and intuitive manipulation GPR datasets to remove structures that interfere with the segmentation process, or simply occlude archaeological features in the visualization.

7.3 Interactive interpretation

All in all, segmentation of archaeological structures in GPR data is still a comparatively laborious process. However, Their, explicit and true to the data evidence is not unconditionally needed. In the interpretative process aiming at the reconstruction of the original state at the time of use, it might not even be desired to obtain the state after destruction or decay.

Therefore, we started to develop software tools extending the commonly used GIS based approach to interpret 3D GPR datasets by drawing polygons onto individual depth or time slices to 3D in 2021.

The resulting toolset facilitates 3D interpretation of GPR data based on drawing contour polygons on top of 3D visualisations. These polygons are extruded, resulting in 3D Polyhedrons, which can be refined by drawing additional polygons using different views and applying Boolean operations like Difference, Intersection or Union as shown below in Figure 33 and 34.

Fig. 33. Initial contour polygon drawn on top of 3D visualisation to delineate the apse of the church before extrusion and applying a Boolean intersection operation with the dataset bounding cuboid.

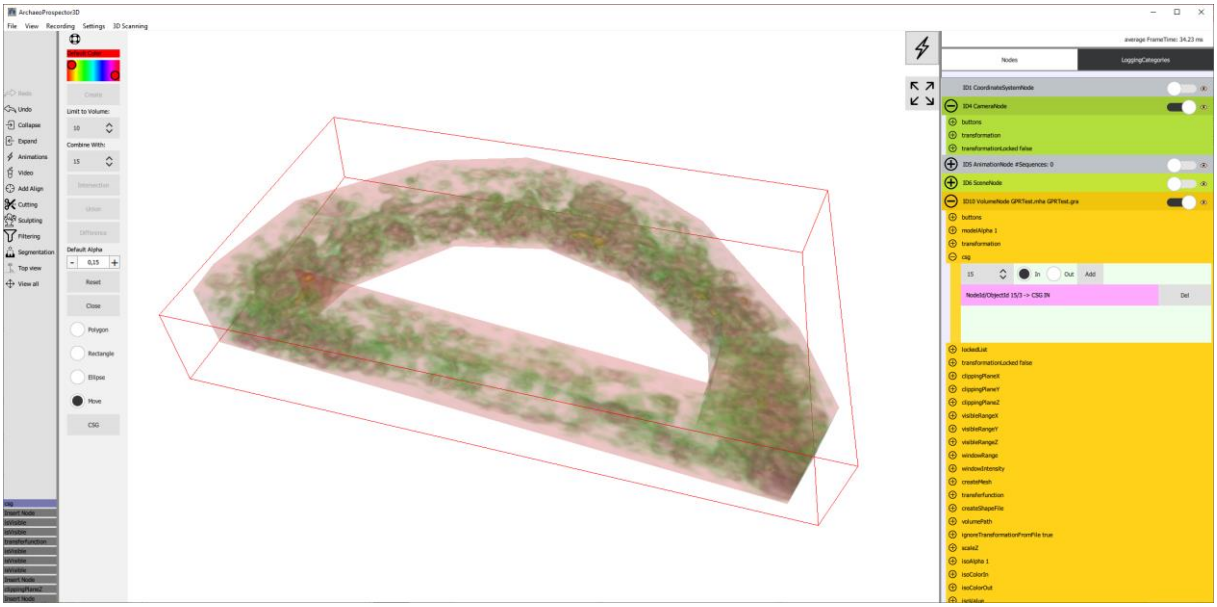

Fig. 34. Interpretation model of the apse after drawing a second contour polygon, extrusion, and apply a difference operation with the previous interpretation model.

In practice this type of interpretation is easy to perform, and, together with local visualisation control of the rendering efficiently supports the delineation of largely convex archaeological structures like walls in 3D visualisation, since this often only requires a coarse 3D model (Fig. 35).

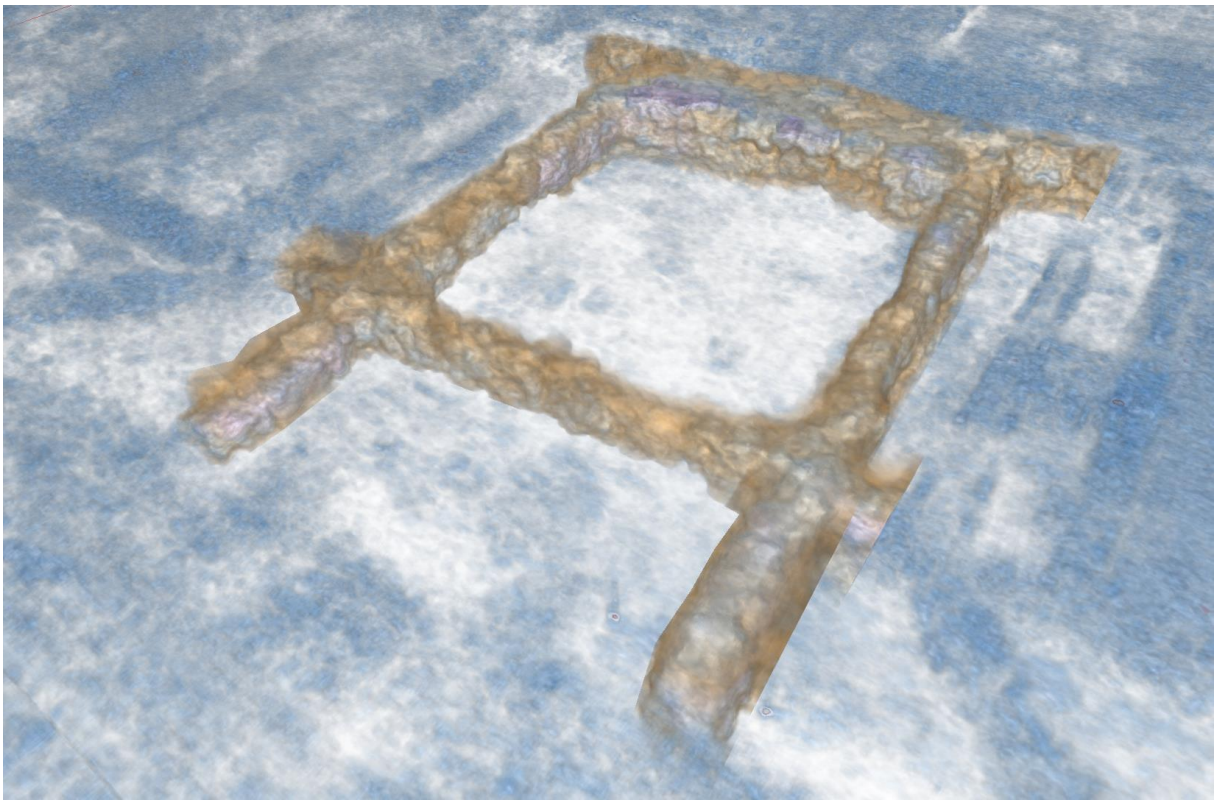

Fig. 35. Walls of one building of the Roman forum in Carnuntum, visually depicted using a coarse 3D interpretation model and local visualisation control, leading to the visualisation of a filtered dataset version inside the wall model. Despite the simple 3D model, the walls are clearly delineated and many details of the wall structure are visible.

8 Reconstruction and Simulation (SIM)

8.1 Open-source desktop planetarium *Stellarium*

A specific focus is set on the integration of architectural and landscape models into the software Stellarium which is able to simulate the sky through time for archaeoastronomical studies. Georg Zotti is co-developer of the popular Stellarium open-source desktop planetarium (https://stellarium.org). Stellarium's quarterly releases are downloaded by approx. 270.000-700.000 users, mostly by amateur astronomers, but also by researchers of cultural astronomy.

In 2021 those final two accuracy issues could be solved which are needed for historical research: accurate planet axes and annual aberration of starlight. Apart from bugfixes, the final development before releasing its long-awaited version 1.0 shall be the upgrading to the new Qt6 programming framework, scheduled for 2022.

A "reference publication" with the state just before these improvements has been published:

- Zotti, G., Hoffmann, S. M., Wolf, A., Chéreau, F., & Chéreau, G. (2021). The Simulated Sky: Stellarium for Cultural Astronomy Research. Journal of Skyscape Archaeology, 6(2), 221–258. https://doi.org/10.1558/jsa.17822

Stellarium is internationally used for astronomical teaching, outreach, and its features include the possibility to represent constellations and star names from other, non-Western cultures. This makes it the most popular tool for dissemination of ethnoastronomical research. At SEAC2021 (Conference of the European Society for Astronomy in Culture) a program extension created by Georg Zotti has been presented which can directly retrieve and display data from several online resources in a web browser view, most notably the re-launched Ancient-Skies database which now aims to be an important pivot in the star naming ambitions recently established in the International Astronomical Union:

- Georg Zotti, Susanne M. Hoffmann, Doris Vickers, Rüdiger Schultz, and Alexander Wolf. Revisiting Star Names: Stellarium and the Ancient Skies Database. In (Proc. SEAC2021). Stara Zagora, Accepted for publication.

9 Spatio-temporal reasoning (STR)

9.1 Harris Matrix Composer (HMC)

In 2021 the LBI ArchPro continued to offer licenses for the Harris Matrix Composer v2.0b and received 46 requests from 19 different countries (Fig. 36 and 37). An interactive overview of the organizations that have acquired an HMC license in the past 13 years can be found under https://harrismatrixcomposer.com/stats/organizations.html.

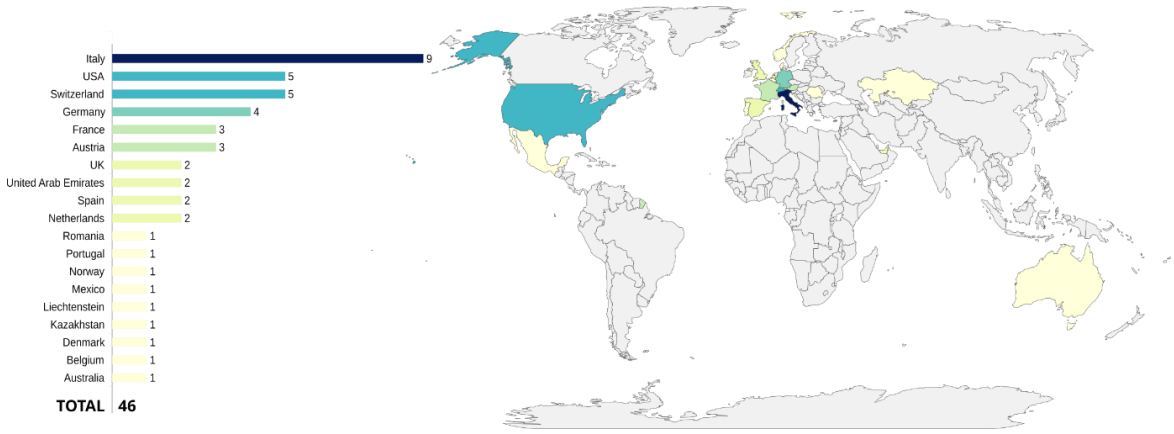

Fig. 36. HMC license requests in 2021.

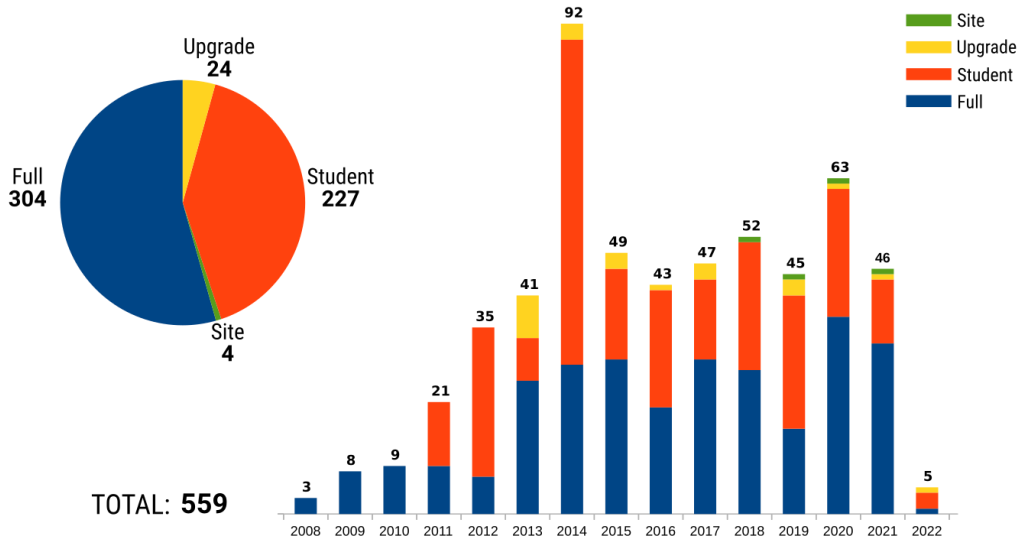

Fig. 37. Total requests of HMC licenses from 10/2008 to 01/2022. Site licenses are multiplied by factor of 10. Student, Full and Upgrade licenses have a factor of 1.

9.2 Harris Matrix Composer Plus (HMC+)

In 2021, the main focus was on improving the user interface and user experience. Several dialogs, forms and workflows have been improved and simplified and new tools have been added:

- Selection Tool: The user can select units based on superposition or Allen-Algebra (Fig. 38).
- Grouping Tool: Closing and expanding all groups at the same time is possible with one click.
- Export Tools: The export to PNG, JPG and PDF is possible.
- Settings: The user can now disable the automatic reduction for transitive relations. Automatic prefixes and suffixes for SUIDs can be specified in the project settings. The year notation format can be changed between Anno Domino (BC/AD) and Common Era (BCE/CE).
- HMC+ Importer: A new importer was implemented to convert tables from Shapefiles to the HMCP-file format (Fig. 39). The support for CSV-files was also started and will be available in 2022.
- GIS Plugin: The plugin was ported to ArcGIS v2.8 and the support for linking tables from Shapefiles was added.

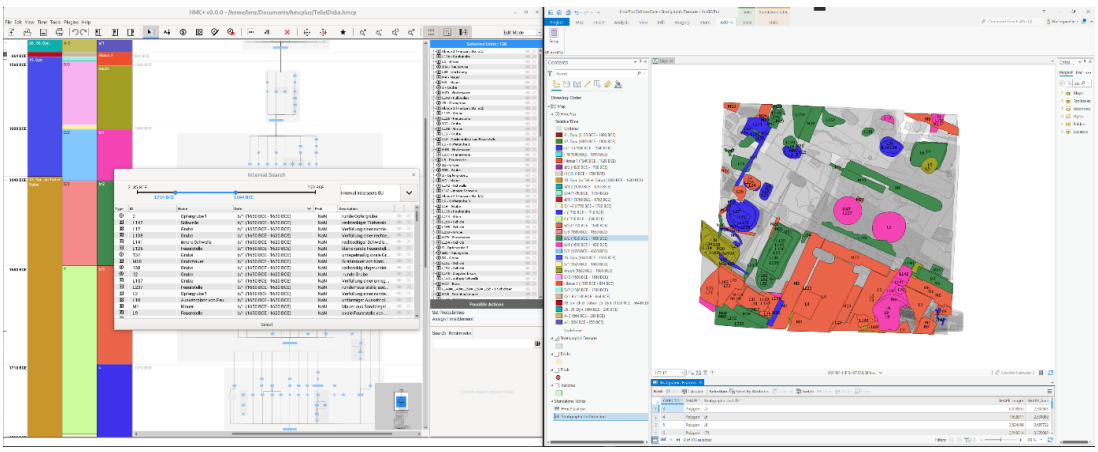

Fig. 38. On the left side is HMC+ with the Allen Selection dialog open. It allows the selection of units utilizing the Allen-Algebra. On the right is ArcGIS Pro 2.8 with the corresponding features associated with the units in HMC+.

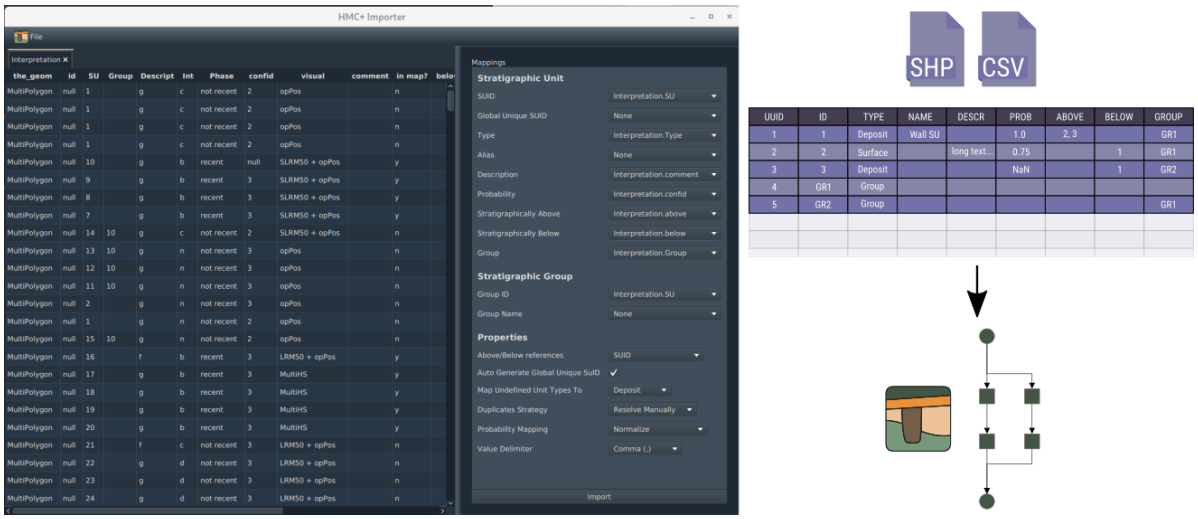

Fig. 39. The new HMC+ importer can import tables from Shapefiles and convert it to a HMCP-file.

9.3 ArcMap Toolbox

A new tool was added to the ArchPro Python-toolbox for ArcMap 10.2. The tool automates the export of map layouts to PNG for a given list of monuments stored in a Shapefile (Fig. 40).

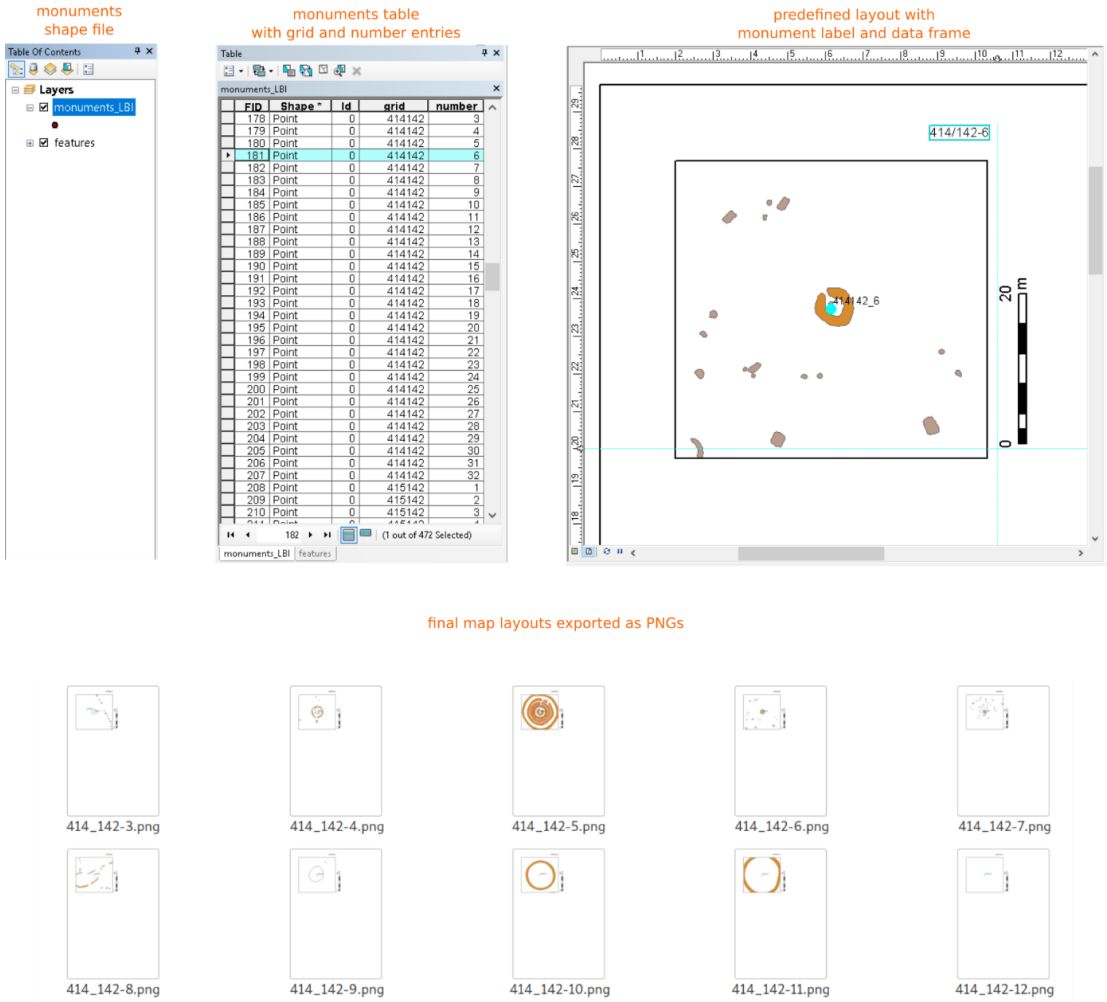

Fig. 40. The Monument-Export-Tool automates the tedious manual export of map layouts in ArcMap.

10 Dissemination and awareness (DISS)

10.1 Press releases

Piber Digital – Digitisation of the immaterial and material cultural heritage around the breeding of the Lippizaner

In February 2021, a joint press release with partner Spanish Riding School was published on the large-scale digitization project of the historical buildings and landscape at the Lippizaner Stud Piber in Styria, Austria that had been carried out by the LBI ArchPro team in fall 2020. The project goal was to digitally transform the tangible and intangible cultural heritage in Piber into virtual space in order to preserve it in the long term, make it accessible to all and use it to promote regional, national and European identity, thus securing it sustainably for future generations.

On the basis of a scientific evaluation, new guided tours and display concepts were developed using modern virtual and augmented reality technologies. As a result, a concept for the redesign of the existing museum at the "Schüttkasten" was realized (see chapter 12.3.1).

Concomitantly, the dedicated project website which has been designed by the LBI ArchPro in collaboration with the Spanish Riding School was updated (https://piber-lbiarchpro.org).

- The point cloud data has been processed into an interactive website with Potree, a web-based point cloud renderer Three main areas were published: Piber Central, Afling, and Stubalm (Fig. 41), and can be viewed under https://piber.lbi-archpro.org/interactive/.
- An interactive overview map of Piber was created with 19 selected points of interest. For each point a short video was shot and published on Youtube. The map is available under https://piber.lbi-archpro.org/#overviewmap and the playlist can be found under https://youtube.com/playlist?list=PLAJQ_9xDM55FSzsDNiuNcwtd5qhutyBnd
- A new blog posts about the museum and its opening was published under https://piber.lbi-archpro.org/blog/museum_piber_folge_der_herde/

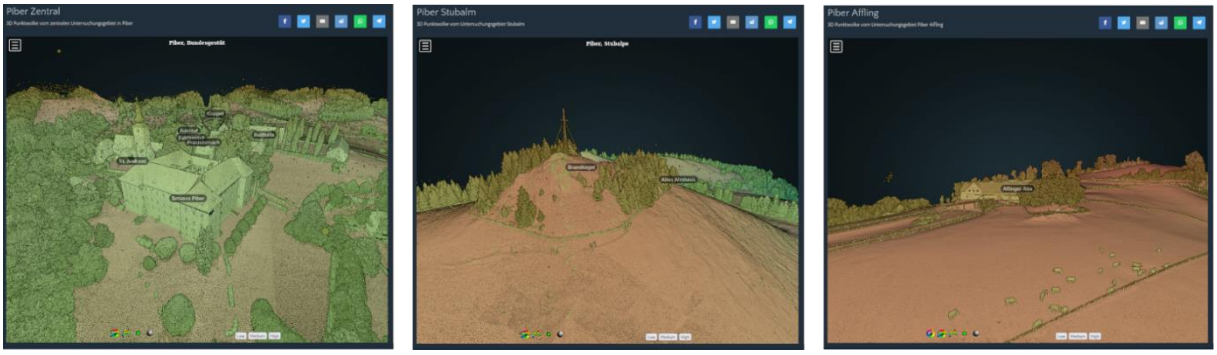

Fig. 41. Interactive 3D point cloud views from the central area, the Stubalm and Afling at the Federal Stud Piber as published on the project website.

10.2 TV productions

Universum History "In den Fängen der Wikinger" (ORF2)

The major international TV project "In den Fängen der Wikinger" was completed for the French-German TV station ARTE with the participation of the LBI ArchPro and broadcast on ORF2 in January 2021. The series features the LBI ArchPro's research on Viking Age sites in Norway and Sweden where high-resolution ALS and geophysical prospection data have revealed new insights into the role

of some of the most important Late Iron and Viking Age sites that challenge current interpretations (Fig. 42).

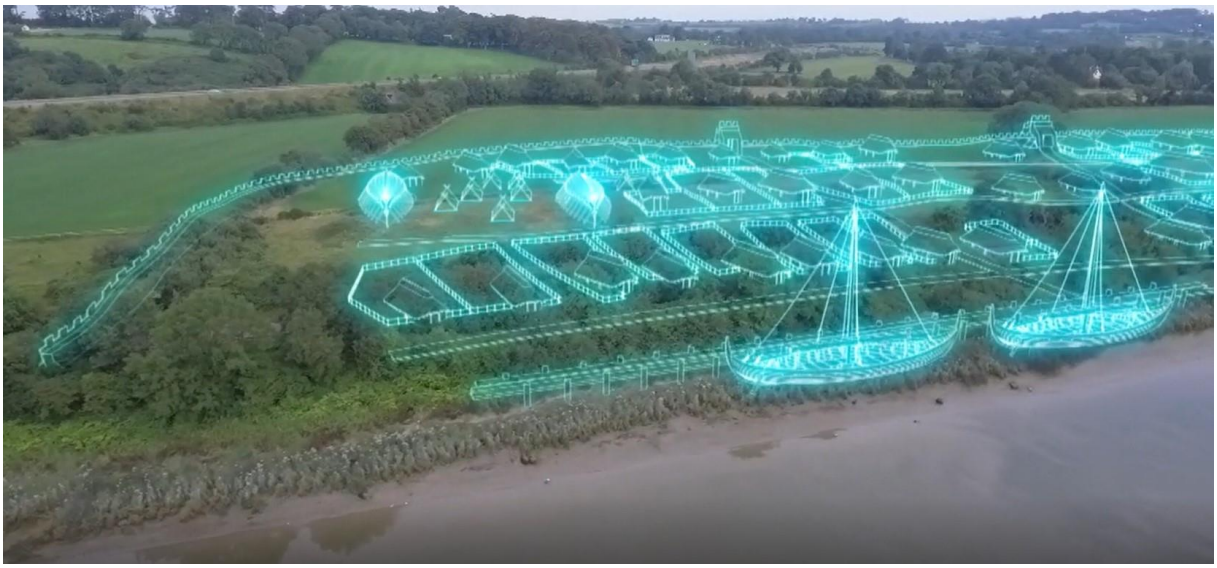

Fig. 42. Scene from the TV series Universum History "In den Fängen der Wikinger".

Terra X „Die verborene Welt von Stonehenge" (ZDF)

A documentary for the ZDF brand Terra X was produced on Stonehenge and broadcast with the title "Die verborgene Welt von Stonehenge" in August 2021. The series featured the research of the Stonehenge Hidden Landscapes project and an interview with director Wolfgang Neubauer.

10.3 Exhibitions

Federal Stud Piber exhibition "Folge der Herde!"

In the museum of the Lipizzaner Stud Piber, the permanent exhibition space was redesigned in cooperation with the LBI ArchPro. In a historic granary, the so-called "Schüttkasten" from 1490, multimedia displays on the intangible UNESCO cultural heritage of Lipizzaner breeding as well as 3D models of the landscape and historical buildings extensively digitised by the researchers tell the long history of the Lipizzaner horses, the Federal Stud in Piber and the Spanish Riding School in Vienna (Fig. 43). The unique, baroque Winter Riding School at Hofburg Palace is also integrated into the exhibition area as a separate large 3D model combined with the projection of a quadrille. Furthermore, a new app – programmed by partner 7reasons and available also in a special quiz version for children - accompanies visitors through the surroundings, interactively explains the structural facilities in the outdoor and indoor areas and offers additional information in the exhibition:

- Folge der Herde https://play.google.com/store/apps/details?id=net.sreasons.piber_kids&gl=AT
- Folge Sigi (for kids): https://play.google.com/store/apps/details?id=net.sreasons.piber&gl=AT

The new permanent exhibition "Folge der Herde!" was opened in September 2021 with a big public event featuring a performance by the Lippizans of the Spanish Riding School.

Fig. 43. Left: 3D landscape model at the new exhibition "Folge der Herde" (Photo: SRS/Rene van Bakel). Right: Representatives of the regional and national government at the exhibition opening (Photo: N. Studnicka).

Stonehenge – Von Menschen und Landschaften (Herne, Germany)

Due to the great success of the exhibition "Stonehenge – A Hidden Landscape" at Austria's MAMUZ museum in Mistelbach, another exhibition on the research work of the LBI ArchPro the Stonehenge Hidden Landscapes Project was designed together with partner LWL and opened at the associated museum, the LWL Museum of Archaeology in Herne, Germany on September 23rd 2021.

Starting from the Mesolithic to the Bronze Age and the modern perception of Stonehenge, a comprehensive presentation of the numerous monuments and their significance in the development of Stonehenge's unique ritual landscape are shown. The core element of the exhibition space are the triliths of the horseshoe in the center of Stonehenge which will be exhibited as replicas on a scale of 1:1 in the 1400 m² large and 9 m high hall. To generate the detailed replicas of the stones, the LBI ArchPro has acquired 3D scans made by Historic England. This purchase notwithstanding, these scans still needed much processing to make them suitable for milling (Fig. 44).

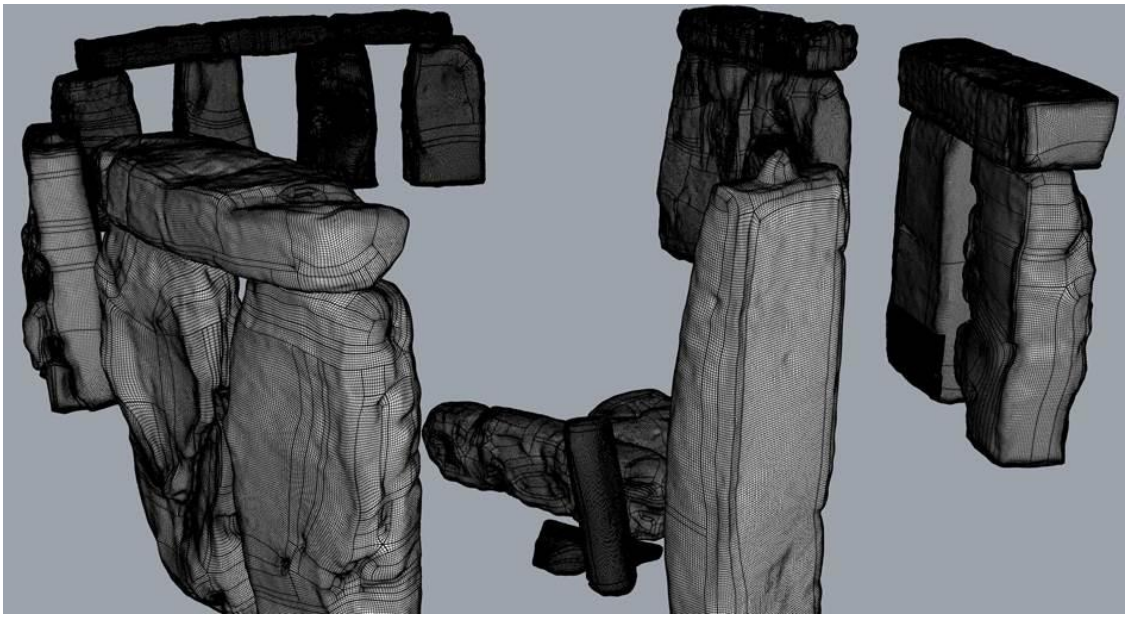

Fig. 44. The 24 resulting NURBS models.

Two landscape models were created for Pixel-Perfect Projection Mapping. The narration on one is identical to the story shown on the (larger) model in MAMUZ. The other shows a closeup of Durrington Walls. Textures have been generated by 7 reasons who also produced and supervised the final setup.

The exhibition is combined with special programs for children and a separate room in which the technological developments in the field of archaeological prospection and virtual archaeology are highlighted.

The LBI ArchPro team contributed eight chapters to the exhibition catalogue which was co-edited by Wolfgang Neubauer (for a detailed list of all contributions see chapter 10.4).

- Mölders, Doreen; Rind, Michael M.; Schierhold, Kerstin; Neubauer, Wolfgang; Richards, Julian (eds) (2021): Stonehenge. Von Menschen und Landschaften: LWL-Museum für Archäologie, Westfälisches Landesmuseum Herne. Michael Imhof Verlag.

Heldenberg Kreisgrabenmuseum

The Heldenberg is a popular tourist attraction in the Weinviertel of Lower Austria. As the venue of the Lower Austrian Provincial Exhibition 2005, a “Kreisgrabenmuseum” was installed under the direction of Prof. Wolfgang Neubauer (Fig. 45) and a Middle Neolithic circular ditch and houses were reconstructed in the open-air area.

In 2021, the refurbishment of the open-air museum and an upgrading of the permanent exhibition in the Kreisgrabenmuseum was started in cooperation with the Heldenberg museum. In a first step, the media stations in the exhibition were updated and extended with new content and new hardware. In the archaeological open-air area of the museum, the outer palisade circle of the Middle Neolithic ditch was redesigned and the state of preservation of the four house reconstructions were assessed (see also chapter 12.3).

The next step will be the integration of virtual and augmented reality applications and the development of new guided tour and presentation concepts.

Fig. 45. The permanent exhibition at the Kreisgrabenmuseum on the Heldenberg.

10.4 Scientific publications and presentations 2021

Articles

Cowley, Dave; Verhoeven, Geert Julien Joanna; Traviglia, Arianna (2021): Editorial for Special Issue: "Archaeological Remote Sensing in the 21st Century: (Re)Defining Practice and Theory". In: Remote Sens. 13 (8), S. 1431. DOI: 10.3390/rs13081431.

Filzwieser, Roland; Aldrian, Lisa; Stadler, Harald; Neubauer, Wolfgang (2021): Burg Schönwerth. Archäologische Re-Prospektion einer wüsten mittelalterlichen Niederungsburg in Volders, Tirol. In: ArchA (105), S. 205–222. DOI: 10.1553/archaeologia105s205.

Filzwieser, Roland; Ivanišević, Vujadin; Verhoeven, Geert Julien Joanna; Gugl, Christian; Löcker, Klaus; Bugarski, Ivan et al. (2021): Integrating Geophysical and Photographic Data to Visualize the Quarried Structures of the Roman Town of Bassianae. In: Remote Sens. 13 (12), S. 2384. DOI: 10.3390/rs13122384.

Gugl, Christian; Radbauer, Silvia; Wallner, Mario; Humer, Franz; Pollhammer, Eduard; Neubauer, Wolfgang (2021): Vor den Toren der Stadt – Struktur und Entwicklung des westlichen Suburbiums der Carnuntiner Zivilstadt. Neubewertung der Notgrabung 1976 aufgrund der geophysikalischen Messungen 2012–2015. In: Carnuntum Jahrbuch 2020, S. 37–84.

Gugl, Christian; Wallner, Mario; Hinterleitner, Alois; Neubauer, Wolfgang (2021): The Seat of the Roman Governor at Carnuntum (Pannonia Superior). In: Heritage 4 (4), S. 3009–3031. DOI: 10.3390/heritage4040168.

Hein, Irmgard; Bühler, Birgit; Ivanova-Bieg, Maria; Kunst, Günther Karl; Mehofer, Mathias; Scharrer-Liska, Gabriele et al. (2021): VIAS – the Vienna Institute for Archaeological Science. In: IANSA XII (1). Online verfügbar unter http://iansa.eu/papers/IANSA-2021-01-vias-the-vienna-institute-for-archaeological-science_onlinefirst.pdf.

Mayr, Ulrike; Schiel, Hannes; Aldrian, Lisa; Filzwieser, Roland; Gamon, Martin; Hinterleitner, Alois et al. (2021): Archäologisch-geophysikalische Prospektion der römischen Villa in Schaanwald. In: Amt für Kultur, Archäologie, Fürstentum Liechtenstein (Hg.): Archäologie in Liechtenstein 2020. Vaduz, S. 89–107.

Schlegel, Jona; Verhoeven, Geert Julien Joanna; Cassitti, Patrick; Hinterleitner, Alois; Löcker, Klaus; Schiel, Hannes et al. (2021): Prospecting the UNESCO World Heritage Site of Müstair (Switzerland). In: Remote Sens. 13 (13), S. 2515. DOI: 10.3390/rs13132515.

Trinks, Immo; Gabler, Manuel; Wallner, Mario; Nau, Erich; Hinterleitner, Alois; Filzwieser, Roland et al. (2021): Traces of a Swedish army camp from 1644 revealed at Uppåkra by extensive magnetometer survey. In: Archaeol. Prospect., S. 1–14. DOI: 10.1002/arp.1842.

Verhoeven, Geert Julien Joanna; Santner, Markus; Trinks, Immo (2021): Bildbasierte 3D-Modellierung der Wandmalerei in der Bischofstorvorhalle im Wiener Stephansdom. In: ÖZKD 75 (1/2), 163–174. DOI: 10.5281/zenodo.5029639.

Wallner, Mario; Löcker, Klaus; Gugl, Christian; Trausmuth, Tanja; Vonkilch, Alexandra; Einwögerer, Christina et al. (2021): The 'Archpro Carnuntum' Project – Integrated Archaeological Interpretation of Combined Prospection Data, Carnuntum (Austria). In: Építés - Építészettudomány (49). DOI: 10.1556/096.2021.00005.

Zotti, Georg; Hoffmann, Susanne M.; Wolf, Alexander; Chéreau, Fabien; Chéreau, Guillaume (2021): The Simulated Sky. Stellarium for Cultural Astronomy Research. In: Journal of Skyscape Archaeology 6 (2), S. 221–258. DOI: 10.1558/jsa.17822.

Book chapters

Banton, Simon; Zotti, Georg (2021): Stonehenge und Astronomie. Eine kurze Geschichte der astronomischen Deutung von Stonehenge. In: Doreen Mölders, Michael M. Rind, Kerstin Schierhold, Wolfgang Neubauer und Julian Richards (Hg.): Stonehenge. Von Menschen und Landschaften : LWL-Museum für Archäologie, Westfälisches Landesmuseum Herne. Petersberg: Michael Imhof Verlag, S. 218–225.

Filzwieser, Roland (2021): Burg und Herrschaft Scharfeneck am Leithagebirge aus landschaftsarchäologischer und historischer Perspektive. Wien, Österreich: Österreichische Gesellschaft für Mittelalterarchäologie (Beiträge zur Mittelalterarchäologie in Österreich, Beiheft 12).

Gibson, Alex; Neubauer, Wolfgang (2021): Gruben, Gräben, Wälle, Durchlässe. Causewayed enclosures auf den Britischen Inseln. In: Doreen Mölders, Michael M. Rind, Kerstin Schierhold, Wolfgang Neubauer und Julian Richards (Hg.): Stonehenge. Von Menschen und Landschaften : LWL-Museum für Archäologie, Westfälisches Landesmuseum Herne. Petersberg: Michael Imhof Verlag, S. 134–141.

Gugl, Christian; Wallner, Mario; Neubauer, Wolfgang (2021): Statthalterpalast und Statthaltergarde - neue Aspekte aus Carnuntiner Sicht. In: Danica Beyll, Wolfgang Hameter, Christine Kandler, Jutta Pietsch und Wolfgang Pietsch (Hg.): Carnuntiner Wege. Festschrift für Manfred Kandler zum 80. Geburtstag. Graz: Unipress Verlag (Römisches Österreich, 44), S. 37–53.

Malter, Tabea; Mölders, Doreen; Neubauer, Wolfgang; Rind, Michael M.; Schierhold, Kerstin; Woschitz, Erich (2021): Prolog: Stonehenge kommt nach Herne! Eine Ausstellung mit Perspektive auf geprägte Landschaften von der Steinzeit bis zur Moderne. In: Doreen Mölders, Michael M. Rind, Kerstin Schierhold, Wolfgang Neubauer und Julian Richards (Hg.): Stonehenge. Von Menschen und Landschaften : LWL-Museum für Archäologie, Westfälisches Landesmuseum Herne. Petersberg: Michael Imhof Verlag, S. 28–34.

Malter, Tabea; Mölders, Doreen; Neubauer, Wolfgang; Rind, Michael M.; Schierhold, Kerstin; Woschitz, Erich (2021): Stonehenge kommt nach Herne! Große Sonderausstellung. In: LWL-Museum für Archäologie (Hg.): Kathedralen der Steinzeit. Stonehenge und die europäischen Megalithkulturen. Darmstadt: wbg Theiss (Archäologie in Deutschland Sonderheft, 22 (2021)), S. 9–12.

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11 Training and teaching (TRAIN)

11.1 Internal training

Image-based modelling training with partner LWL

Many theoretical and practical insights in the field of image-based modelling have been shared with the staff of the Landschaftsverband Westfalen-Lippe. They photographically documented a vessel's excavation, while the LBI ArchPro developed the RAW photographs and generated the 3D models of these images. All 3D models of all excavation stages have been computed and shared with LWL.

PhD candidate internship at partner NIKU

In September 2021, David Russ - LBI ArchPro employee and PhD fellow of the Initiative College for Archaeological Prospection (IC ArchPro) – completed a 3-week internship with partner NIKU as required in the programme's curriculum. In line with his dissertation topic ("Der (protourbane?) Fundort Kaupang, Norwegen: Landschaftsarchäologische Analyser eines zentralen Fundortes der Wikingerziet in Südskandinavien an Hand von Prospektions- und Grabungsdaten"), his tasks included GPR measurements at important Viking Age sites in southern Norway (e.g., Jellestad), GPR data interpretation and networking with Norwegian and international experts and colleagues.

11.2 University field schools

Linear Pottery settlement of "Kleinhadersdorf" (Lower Austria)

In summer 2021 another university field school was conducted in cooperation with the University of Vienna at Kleinhadersdorf over the course of four weeks. The field school aimed at teaching bachelor and master students modern stratigraphic excavation and digital three-dimensional documentation techniques (Fig. 46).

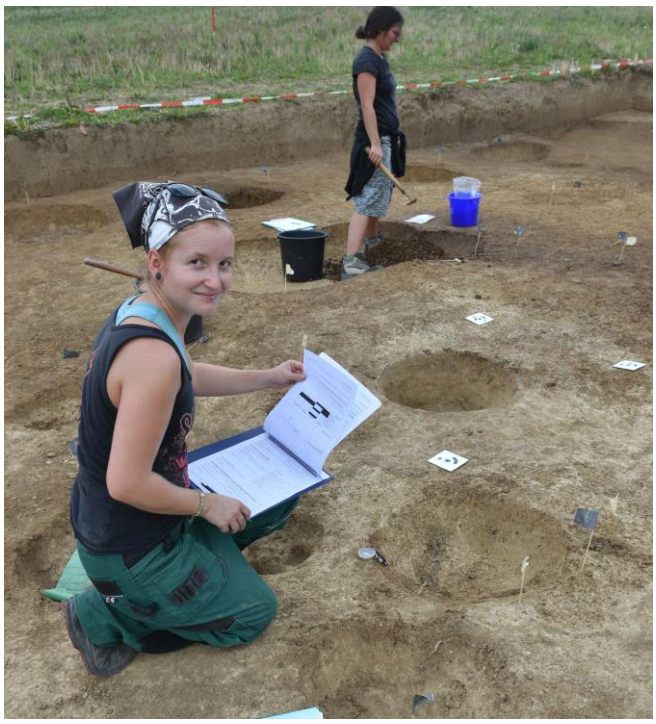

Fig. 46. Student assisting with the documentation process.

University field school at the Late Bronze Age settlement „Königsberg“ in Tieschen (Styria)

The prehistoric site „ Königsberg“ in Tieschen is one of the largest fortified settlements in southern Styria. The hilltop settlement located on the summit of the Königsberg dates back to the Late Bronze Age and covers an area of approximately 10 ha. The fortification, consisting of ditches and earthen ramparts, is still clearly visible in the landscape today. Within the new research project "Archaeological Heritage Königsberg", the prehistoric settlement is investigated using interdisciplinary methods for the first time. Prior to the excavation a high-resolution GPR survey of the selected area had been conducted, revealing archaeological features extending to a depth of 1.2 meters (3-channel 500 MHz handheld system).

The stratigraphic excavation in July 2021 was carried out in close cooperation with the University of Vienna and the municipality of Tieschen. Five advanced-level students, one Erasmus+ intern and one student intern funded by the FFG Talente program participated in the four-week field school. During the excavation, an area of approximately 150 m² inside the Late Bronze Age settlement was exposed and numerous archaeological structures and finds could be documented three-dimensionally. Image-based modelling and terrestrial laser scanning formed the basis of the archaeological documentation workflow. The participants of the field school were trained in the different areas of archaeological fieldwork and digital documentation (Fig. 47).

An important aspect of the project was focused on science communication and the involvement of the general public. Local volunteers were able to help the archaeologists with the excavation on a daily basis, and a weekly open excavation day was organized. Visitors could partake in guided tours and take a look at the most beautiful finds of the ongoing excavation.

In September 2021, the project website for the Königsberg (Tieschen) was launched and is available under https://koenigsberg.lbi-archpro.org/.

Fig. 47. Left: Laserscanning on site. Right: View of the excavation trench at the Königsberg.

11.3 Internships

In 2021 the LBI ArchPro offered several opportunities to students to gain research and work experience in the fields of archaeological prospection and virtual archaeology. The interns were guided by the dedicated LBI ArchPro team as they worked on their respective internship projects.

Archaeological excavation and 3D documentation of archaeological excavation data

During the field schools at Kleinhadersdorf and Königsberg/Tieschen a team of advanced-level archaeology students of the University of Vienna supported the LBI ArchPro scientific staff with various tasks such as the 3D documentation of the excavation and assisted in teaching and instructing undergraduate field school students on site.

- The archaeological field assistants included Miriam Feichtinger, Janine Gaida, Valentina Laaha, Elias Bele, David Simböck and Stephanie Horvath.
- David Scheucher and Nina Kerschner completed a 4-week school student's internship funded by the **FFG *Talente*** programme.
- International student Kaja Božič (SL) participated in the excavations during a three-month **Erasmus+ student mobility traineeship**.

All interns actively participated in all excavation activities with a focus on the digital documentation, in situ measurements of chemical and physical parameters of archaeological deposits and sampling.

Supervisor: Wolfgang Neubauer

FEMtech intern Klara Sauter continued to work on the GIS-based stratigraphic analysis and visualisation of geodetic and photogrammetric documentation data obtained during the excavation of the middle Neolithic ring ditch Hornsburg 1. Her tasks included data processing (registration and georeferencing, data cleaning, triangulation and texturing of TLS data and image-based modelling point clouds), building a stratigraphic sequence with linked GIS-based 2.5D single plan views, 3D volume modelling of single deposits and generation of 3D animations.

Supervisor*:* Wolfgang Neubauer

Archaeological geophysical prospection and integrated archaeological interpretation

During her **FEMtech** internship Katharina Riederer worked on the integrated archaeological prospection of the Roman settlement Winden am See (Burgenland) using ALS, magnetic and GPR-prospection and geodata. Her tasks included the processing of ALS data and terrain/landscape modelling, data fusion (DTM, MAG, GPR), 3D volume visualisation of fused prospection data and semi-automated segmentation of archaeological structures.

Supervisor: Alexander Bornik

11.4 University lectures

Table 1 lists the academic lectures and courses held by LBI ArchPro staff at the University of Vienna in 2021:

Wolfgang Neubauer	Summer 2021	• 060089 LP Lehrgrabung 2 (Kleinhadersdorf/NÖ, Linearbandkeramik-Siedlung • 060089 LP Lehrgrabung 2 Königsberg, Tieschen • 060069 SE Seminar Abschlussarbeit • 060073 KU Angewandte Vermessungskunde und Stratigraphie
	Winter 2021	• 060055 SE Seminar Abschlussarbeit I
Immo Trinks	Winter 2021	• 060029 VO Einführung zu archäologischen Prospektionsmethoden • 060032 VO Naturwissenschaftliche Methoden der Archäologie: Archäometrie • 060066 VO Magnetische archäologische Prospektion • 060068 UE Archäologische Prospektion mit dem Bodenradar
	Summer 2021	• 060044 VO Einführung zu archäologischen Prospektionsmethoden • 060075 VO Archäologische Prospektion mit dem Bodenradar
Matthias Kucera	Summer 2020 Winter 2020	• 060057 UE Experimentelle Archäologie in der Praxis • 060034 VO Experimentelle Archäologie
Klaus Löcker	Summer 2021	• 060051 KU Kurs zu Grundlagen der Vermessung und der Stratigraphie
Geert Verhoeven	Winter 2021	• 060103 KU Image-based modelling for archaeology
Michael Doneus	Winter 2021	• 060043 UE GIS-Anwendungen in der Archäologie • 060042 UE Luftbildarchäologische Interpretation • 060052 UE Vertiefende Übung zur wissenschaftlichen Praxis • 060053 SE Seminar Abschlussarbeit • 060067 UE Flugzeuggetragenes Laserscanning (LiDAR) für Archäolog*innen
	Summer 2021	• 060056 UE GIS-Anwendungen in der Archäologie • 060063 SE Archaeological Methodologies for Human-Ecodynamics • 060068 UE Vertiefende Übung zur wissenschaftlichen Praxis • 060069 SE Seminar Abschlussarbeit • 060079 VO Landschaftsarchäologie

Tab. 1. Academic lectures and courses held by LBI ArchPro staff.

12 Third party funded research projects

12.1 Kleinhadersdorf

Title: Kleinhadersdorf – Siedlungs- und wirtschaftsarchäologische Untersuchung der linearbandkeramischen Fundstelle Kleinhadersdorf, NÖ
Funding programme: Land NÖ
Duration: 2020-2022
Project lead: LBI ArchPro

In continuation to the excavation project at the Kleinhadersdorf linear pottery culture settlement site which had started in 2020, another research excavation was conducted in cooperation with the University of Vienna over four weeks in summer 2021.

With the results of large scale archaeological geomagnetic surveys (32.3 ha, LBI ArchPro 2017-2018) the second trench (Schnitt 2) could also be precisely placed over one isolated Neolithic house structure (Haus 3) to investigate the special stratification of this site, which encompasses almost 5 ha, to evaluate the quality of ground conservation, to examine the dating of the selected house structure with a focus on settlement continuity and to gain relevant information regarding settlement and economic archaeological issues.

Fig. 48. View of the excavation trench at Kleinhadersdorf.

During the excavation of this 250 m² spanning trench the structure of house 3 was exposed in its south-eastern half and its structures scientifically examined completely (Fig. 48). Complementary susceptibility measurements were undertaken after the topsoil was removed and an almost perfect match with the magnetic und susceptibility data was revealed. Analysis of the finds corroborated a periodisation of the site into the Early Neolithic Period and especially the Linear Pottery culture. The excavated surfaces were digitally documented by image- based modelling and laser scanning and generated a new set of data, which again led to a significant improvement in the understanding of the site.

Additionally, the scientific analysis of the artefacts recovered during the three-year excavation project in Kleinhadersdorf (2020-2022) will shed light on the presumed contemporaneity of the site with the adjacent burial ground, which had been investigated in the 1930s and 1980s.

12.2 MAMUZ

The reconstruction model of an early medieval rotunda with apse at MAMUZ in Lower Austria

Title: Bau der Rekonstruktion einer frühmittelalterlichen Kirche (Rotunde) nach dem Vorbild der Kirche in Pohansko, Mähren im Freigelände des MAMUZ Schloss Asparn/Zaya
Funding body: MAMUZ museum
Duration: 2021-2022
Project lead: LBI ArchPro

An archaeological find from a church excavated between 2008 and 2012 in the north-eastern part of the Great Moravian settlement in Pohansko near Břeclav in what is now the Czech Republic served as a model for the reconstruction model of an early medieval rotunda in the open-air museum Asparn in Lower Austria. Construction work was started by the LBI ArchPro in March 2021 using methods and techniques of experimental archaeology. The building site was in the south-western part of the castle gardens in Asparn and was on a slight slope. Like the original finding, the main axis of the church with the apse should be aligned in an easterly direction towards sunrise.

For the reconstruction project, early medieval tool types were recreated on the basis of archaeological finds to test them in practice on site for their possible uses and resilience. The construction process of the church model was documented with a RIEGL laserscanner during different stages of construction to support the production of virtual animations and to make erosion changes visible over time.

The church was furnished in spring 2022 and opened to the public at the end of March 2022 (Fig. 49).

Fig. 49. Left: The supporting structure of the round church was made of wood; Sill beams were placed on the stone walls of the foundation, the wall surfaces were closed with wickerwork and then mortared and covered with a thatched roof. Right: The furnishings of the round church included a surrounding bench, altar barriers, an altar, a lectern, wooden candlesticks, torch holders and an altar cabinet, which were made according to early medieval models.

12.3 Heldenberg

Redesign of the reconstruction model of a Middle Neolithic circular ditch and the prospecting of four house reconstructions

Title: Revitalisierung des Museums am Heldenberg, Niederösterreich
Funding body: Heldenberg Vermarktungs- und Betriebsgesellschaft mbH
Duration: 2021-2022
Project lead: LBI ArchPro

The Middle Neolithic circular ditch and the four archaeological house models of the Middle Neolithic were built between October 2004 and spring 2005 by an experimental archaeological team from the University of Vienna. The archaeological open-air area was a core element for the Lower Austrian provincial exhibition in 2005.

Commissioned by the community of Heldenberg the LBI ArchPro completed the investigations on the reconstructed house models and presented a comprehensive report by mid-2021. Particular interest was given to the respective state of preservation of the earth-fixed post positions as the stability of the houses depends directly on them.

Above all, it was necessary to clarify the extent to which this decomposition process had already attacked the wood of the vertical components by means of targeted prospecting of the post parts stuck in the ground, so that appropriate conservation measures could be taken in good time. A refurbishmeht plan was drawn up based on the results of the investigation.

In addition, the LBI ArchPro performed the decorative redesign of the outer post circle of the circle ditch system, with the intention of reusing the old stock of timber (Fig. 50. right). All wooden parts show traces of processing that correspond to those of Neolithic tool types.

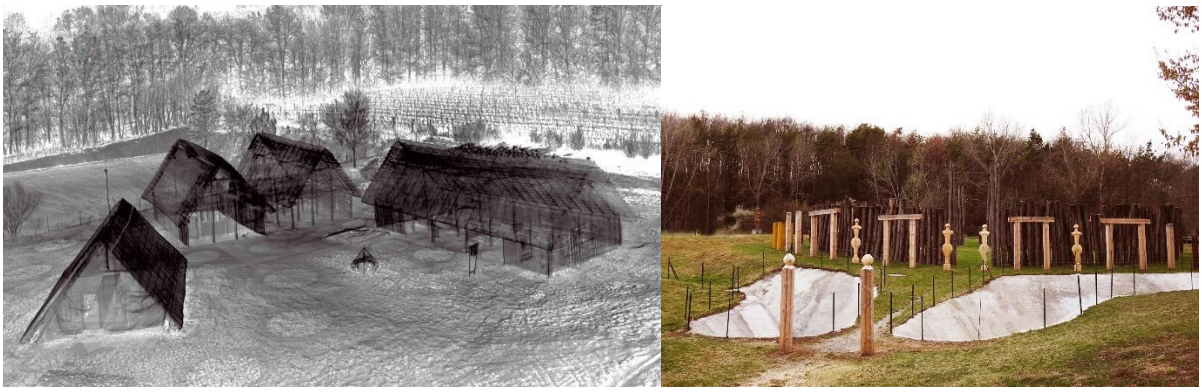

Fig. 50. Left: Riegl scanner: point cloud - measurement of the four Middle Neolithic house models on the Heldenberg. Right: The outer palisade circle of the Middle Neolithic circular ditch was redesigned with a total of four wooden gates and four larger-than-life idol figures made of wood.

12.4 InfoSYS

Title: InfoSYS - GIS based Counter IED/UXO Information System
Funding programme: FFG FORTE
Duration: 07/2020-06/2022
Project lead: LBI ArchPro

The experimental R&D project InfoSYS centers on the conception and development of a prototype of an innovative GIS based counter IED/UXO information system. It will extend conventional sensors used by the Austrian Armed Forces (Amt für Rüstungs- und Wehrtechnik) with remote sensing systems (LiDAR) and motorized, automatically positioned sensor arrays (magnetic, electrical, acoustic and electromagnetic) adapted by the LBI ArchPro for the exploration of archaeological cultural heritage and engineering geophysics.

Upon completion of the geophsysical prospection surveys on various test sites involving different sensor systems in 2020, a software was developed to process the magnetic data of the Foerster and SenSys systems used by the Austrian Armed Forces for a QGIS-plugin. Additionally, terrestrial laser scan surveys were carried out in the area of the battlefield "Dorf" in Kaisersteinbruch to obtain high-resolution 3D terrain and surface models as reference data for topographical information (Fig. 51).

Fig. 51. TLS survey at the battlefield "Dorf" in Kaisersteinbruch.

For the conjoint visualization of heterogeneous archaeological prospection data, the 3D visualization software developed by the LBI ArchPro was adapted to the needs in the InfoSYS context, e.g. the possibility to integrate information on the 3D position and orientation of magnetic dipoles computed from 2D magnetics images into 3D GPR visualizations (Fig. 52). Such visualizations are intended to support experts at the user's site in assessing the IED/UXO hazard situation.

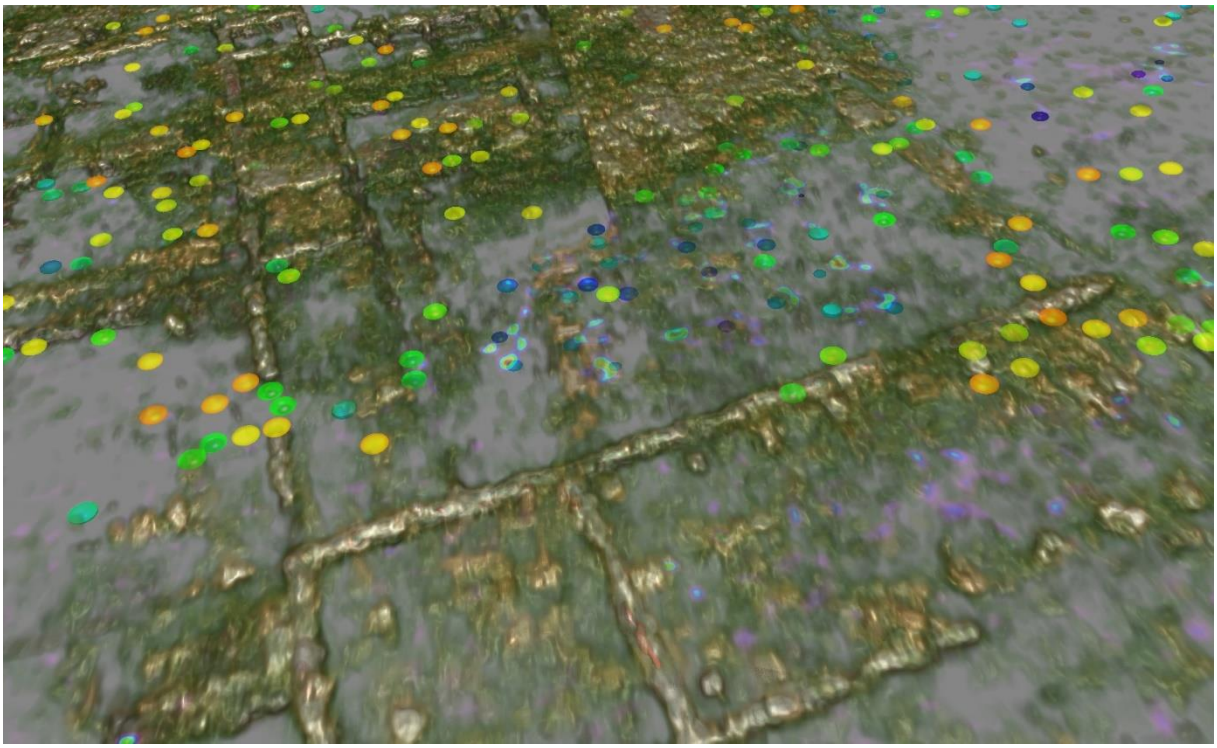

Fig. 52. Visualization of 3D position and orientation of magnetic dipoles computed from 2D magnetics images integrated into 3D GPR visualizations.

Within the task of Navigation of the project, ALS point datasets were utilized for visualisation and path planning. The main test dataset was obtained at the LBI ArchPro case study site Piber and consists of 1.645.958.117 points sampled into a 5cm grid which sum up to roughly 50GB. The huge amount of data presented a challenge for the following visualisation and path planning tasks.

In a first step, storage possibilities were investigated which are suitable for visualisation and path planning, allow to store and retrieve parts of a large dataset and maintain performance and efficient storage at the same time. With TileDB (https://tiledb.com/) a suitable system was found for these requirements. Therefore, ALS point datasets were converted to a voxeldata grid and the results were stored with TileDB (Fig. 53).

The project is conducted in collaboration with the Austrian Armed Forces and partner ZAMG.

Fig. 53. Visualisation of a voxelized ALS point dataset, loaded from TileDB. This sub-dataset consists of 9.147.914 points which are converted to a voxelgrid of size 2527 x 2399 x 351 with a spacing of 0.2 m. The saved TileDB arrays has a size of roughly 300MB.

12.5 Living Danube Limes

Title: Valorising cultural heritage and fostering sustainable tourism by LIVING the common heritage on the DANUBE LIMES as basis for a cultural route
Funding programme: EU Interreg DTP
Duration: 07/2020-12/2022
Project lead: Danube University Krems

The project is centred around the Roman Danube Limes as transnational cultural heritage of enormous significance. Spanning the whole Danube region, the project aims at further developing and enhancing the connecting aspects of the Roman heritage sites along the river, thus, fostering a common sense of togetherness in the Danube Region. To achieve this, all partners will collaborate on the exploration and protection of cultural sites as well as the development of green and sustainable tourism and cultural route solutions.

In fall 2021, the LBI ArchPro investigated selected Roman sites in five project partner countries using geophysical prospection methods (Fig. 54). During fieldwork, image material was collected to be used for 3D-modelling of the pilot sites and for various communication activities in the project. All data will contribute to the subsequent creation and implementation of VR reconstructions for pilot sites in 2022.

For a more detailed report on the fieldwork results see chapter 2.1.

Fig. 54. GPR-survey at the Living Danube Limes pilot site Százhálombatta (HU).

12.6 INDIGO

Title: INventory and DIsseminate Graffiti along the DOnaukanal
Funding body: Austrian Academy of Sciences
Programme: Heritage Science Austria
Duration: 09/2021-08/2023
Project lead: LBI ArchPro (Geert Verhoeven), TU Wien

Despite its long history, the phenomenon of graffiti remains fascinating and debatable because it continually fluctuates between tangible and intangible heritage, vandalism and art, graphical and textual, legal and illegal, subversive and humorous, pleasingly acceptable and socio-political criticism. These contradicting features are also present along the *Donaukana*l (Eng. Danube Canal) in the city centre of Vienna (Austria). The public surfaces surrounding this central waterway have constituted a graffiti hotspot since the early 1980s, with works ranging from colourful murals, anarchistic symbols on bridge pillars to bike stand writings (Fig. 55).

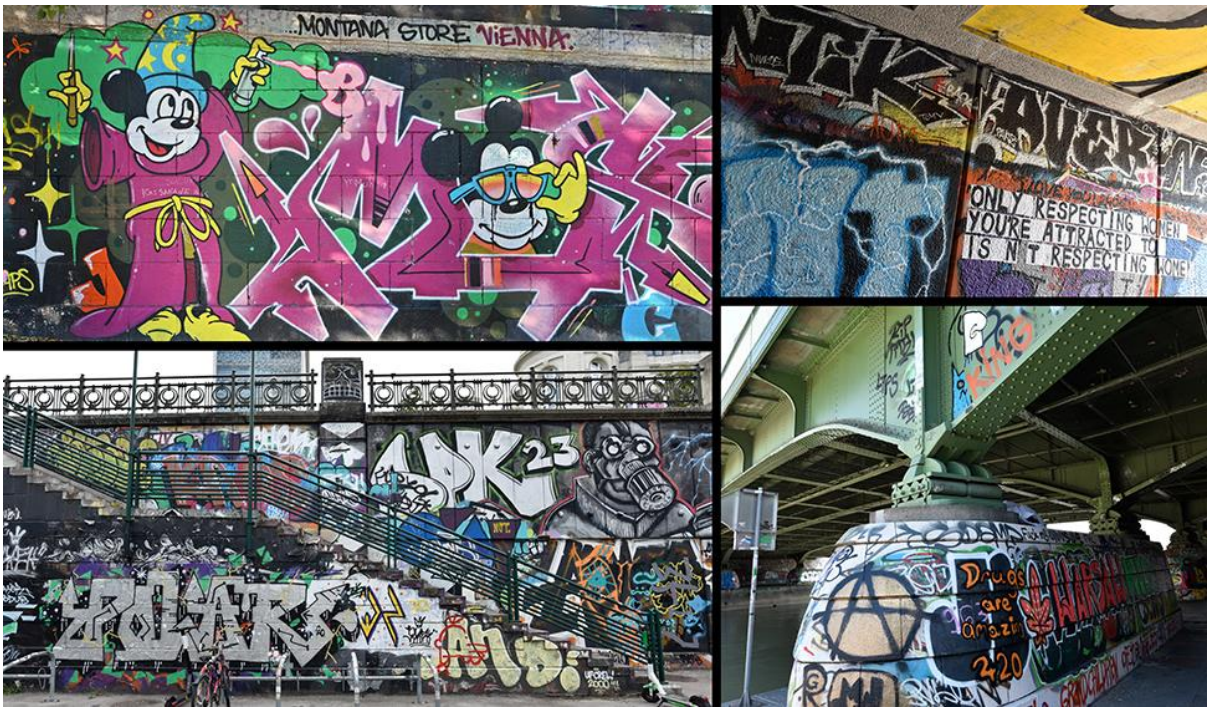

Fig. 55. The large variation in graffiti at the Donaukanal.

Every day, new graffiti appear along the Donaukanal. However, a graffito's mere creation automatically implies the (complete or partial) destruction of one or more existing graffiti beneath. Although graffiti are subject to similar post-depositional processes found on archaeological sites and in landscape formation, one does usually not 'excavate' a graffiti-scape. Pre-existing graffiti simply become a lost and forgotten part of the Anthropocene's global stratification. That is why in the summer of 2020, the idea arose to monitor, digitally safeguard, and analyse a large part of this unique, complex, ever-changing, and socially fascinating cultural heritage that flanks Vienna's central waterway. More than a year later, this concept culminated in the international and interdisciplinary academic project INDIGO: IN-ventory and DI-sseminate G-raffiti along the d-O-naukanal.

Project INDIGO was launched in September 2021. Funded by the Heritage Science Austria programme of the Austrian Academy of Sciences (ÖAW), this two-year project aims to build the basis to systematically document, monitor, disseminate, and analyse a large part of the graffiti-scape along Vienna's Donaukanal in the next decade. INDIGO focuses on nearly 13 km of continuous graffiti-covered urban surfaces between the Friedensbrücke and Verbindungsbahnbrücke (Fig. 56): 5.3 km

on the left and 7.6 km on the right bank. Circa 2/3 of these surfaces are formed by walls, staircases, bridge pillars and ramps surrounding the Donaukanal. However, 4.4 km of this graffiti-scape are found just above the water level on the concrete embankments that contain much of the channel. Strikingly, graffiti are only legal over a combined stretch of less than 300 m (see Fig. 56).

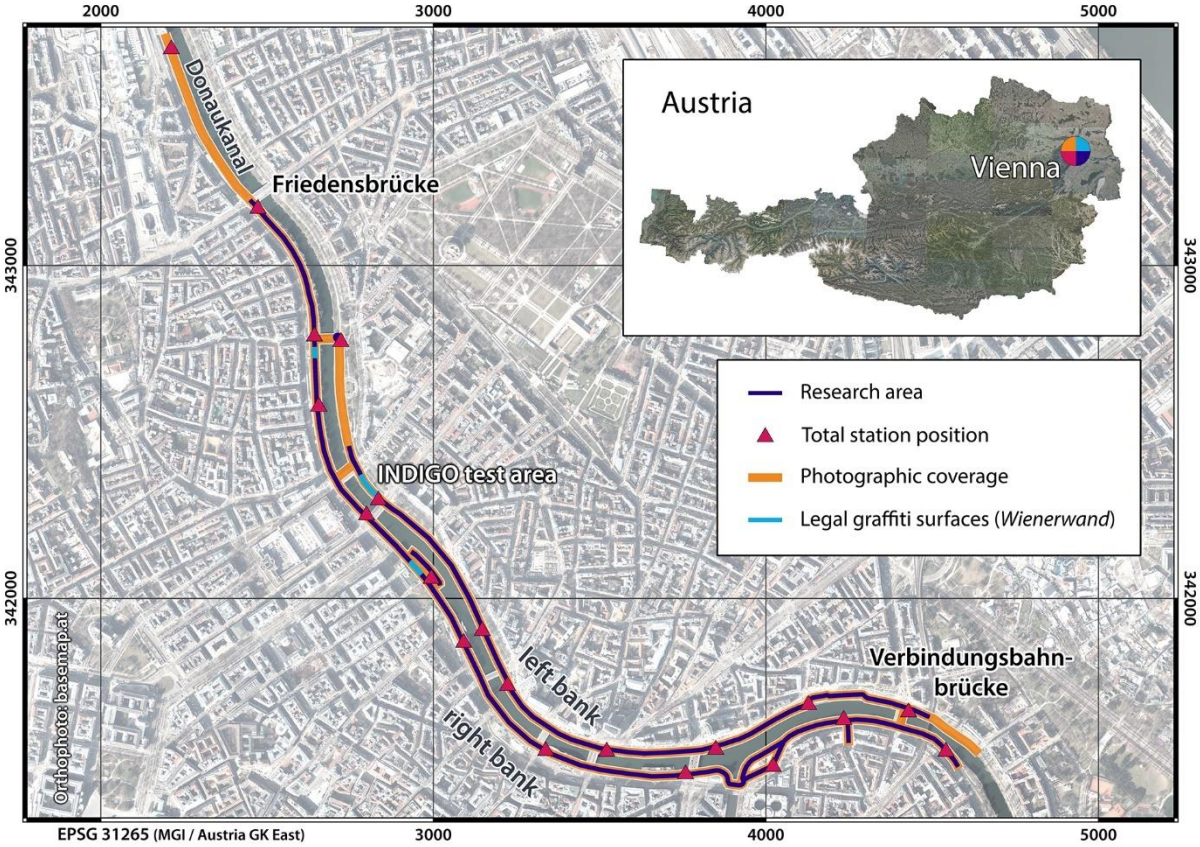

Fig. 56. The INDIGO research zone in the centre of Vienna.

In this diverse research zone, INDIGO operates with three central aims:

1. Documenting the geometrical (i.e. shape and dimensions), spectral (i.e. colour), geographical (i.e. location), temporal (i.e. time of creation and lifespan) and contentual (i.e. subject matter and meaning) aspects of this graffiti-scape along Vienna's Donaukanal to digitally preserve and monitor this volatile and peculiar cultural heritage.

2. Disseminating this distinctive graffiti-scape through the creation of a spatial database and open access online platform that facilitates interactive, multi-temporal querying and visualisation of all graffiti records.

3. Analysing the (meta)data stored in the spatial database to disclose new socio-political-cultural research questions and graffiti-specific insights.

INDIGO thus aims to mirror the real public urban space in the virtual public space of the internet to digitally preserve and investigate an urban graffiti-scape in time and space. Since this exploration leverages numerous graffiti recordings that digitally encode the stratified graffiti-scape, INDIGO can be considered an unconventional archaeological or heritage science project dealing with the contemporary past. However, using the words '(contemporary) graffiti' and 'archaeology' in one sentence is not something that goes undebated, but INDIGO takes the stance that archaeology is an academic discipline trying to understand (our complex relationships with) the material remains of the stratified past, whether that past was centuries (i.e. the remote or ancient past) or days (i.e. the

contemporary or recent past) ago. And graffiti research aptly illustrates that view because there is considerable overlap between the research aims and methods for prehistoric rock art, medieval church carvings and present-day mark-making activities like spraying or pasting stickers.

To accomplish its aims, INDIGO is structured around five research pillars: 1) acquisition, 2) processing, 3) management, 4) dissemination and 5) analysis (Fig. 57).

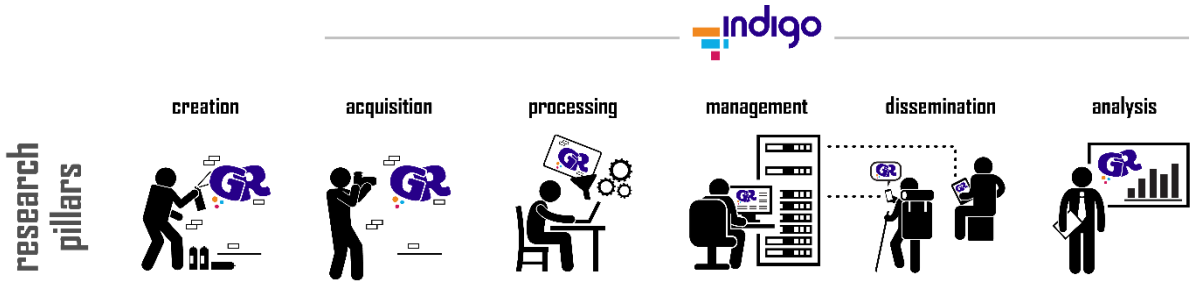

Fig. 57. Infographic showing the major research pillars of INDIGO.

The following enumeration will give some of the results of the first four project months:

- a vibrant and ample illustrated project website is available at https://projectindigo.eu
- INDIGO considers academic transparency to be a top priority. That is why every second week, a Newsletter is launched at https://projectindigo.eu/news/#newsletters. This Newsletter shares upcoming meetings and provides links to all protocols of past meetings (e.g. Fig. 58Fig.).

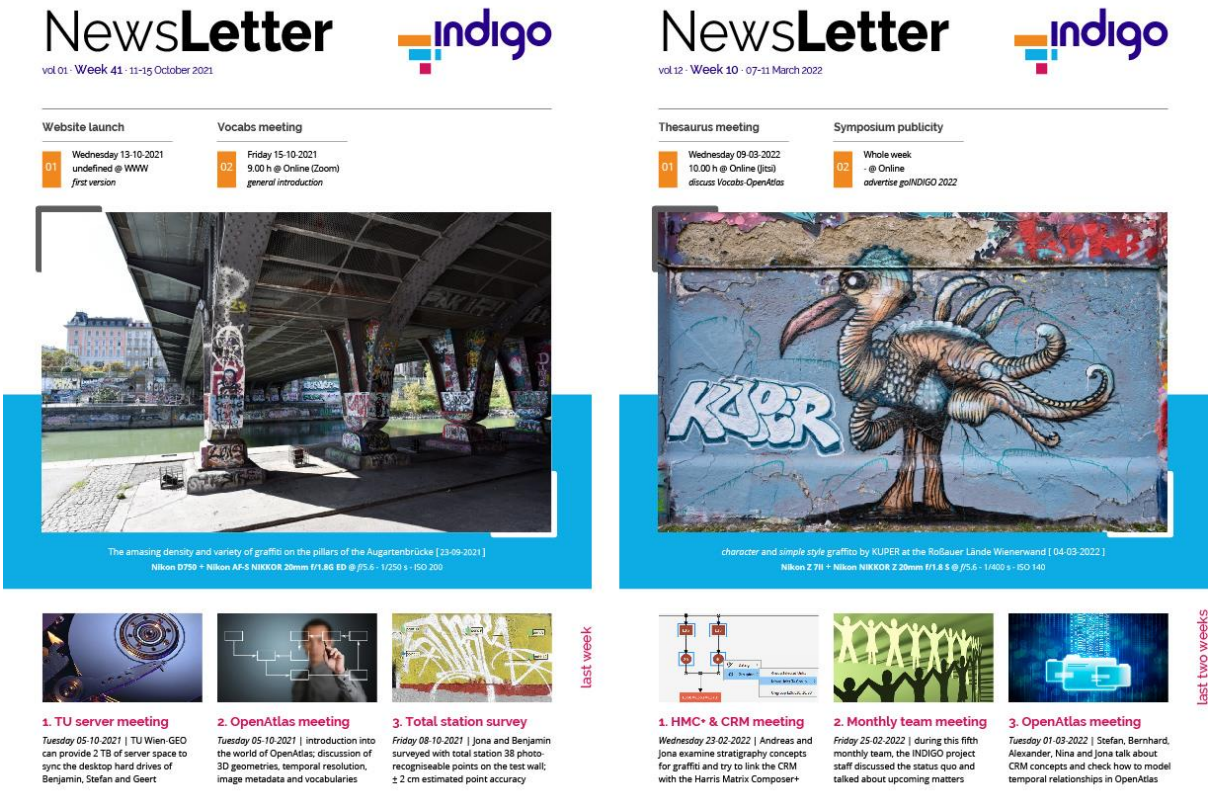

Fig. 58. Example of two INDIGO newsletters.

- given the topics of its research, INDIGO puts much effort into the design of deliverables and other materials. For instance, the colour palette of the logo is used exclusively on the website, presentations and illustrations made within INDIGO (e.g. Fig. 56, 57, 58).
- INDIGO achieved a total photographic coverage of the Donaukanal in October (Fig. 59). All 26.7 photographs were oriented with a dense network of ground control points – collected during several total station surveys. From these photographs, the base 3D surface model will be generated. In addition, these photographs constitute the starting situation from which new graffiti get monitored. In this way, INDIGO is advancing image-based modelling methods for enormous image collections and developing methods for the detailed recording of fast-changing cultural heritage.

Fig. 59. The location of all photographs acquired around the Marienbrücke (Marien Bridge) is indicated in semi-transparent blue. The location of the depicted Nikon Z7 II and Nikon D750 photographs is shown via a red rectangle. The scene's structure is represented by a cleaned cloud of 3D tie points.

- INDIGO is working on a semantically structured database using CIDOC's CRM ontology. Much effort is put into the interoperability of the database – implemented in OpenAtlas (https://openatlas.eu) – with other semantic tools like SKOS (used for INDIGO's graffiti thesaurus) and visualisation tools like LBI ArchPro's HMC+. Much of this is covered in the PhD research of LBI ArchPro researcher Jona Schlegel.

- INDIGO met with the ethical commission of the TU Vienna to discuss ethical topics related to the recording and dissemination of graffiti records.
- INDIGO has set up a graffiti literature database (both in Citavi and Zotero). Over time, the intention is to grow this into a reference database for academic graffiti literature;

the first Python-based scripts that will allow an entire colourimetric image workflow in the form of a Python-based software (called coolpy) are programmed (Fig.60). Besides academic transparency, INDIGO wants all its deliverables to be open access. That is why coolpy is entirely open source and shared via GitHub. In this way, the entire heritage community can utilise the tools INDIGO develops for the colour-accurate processing of digital photographs.

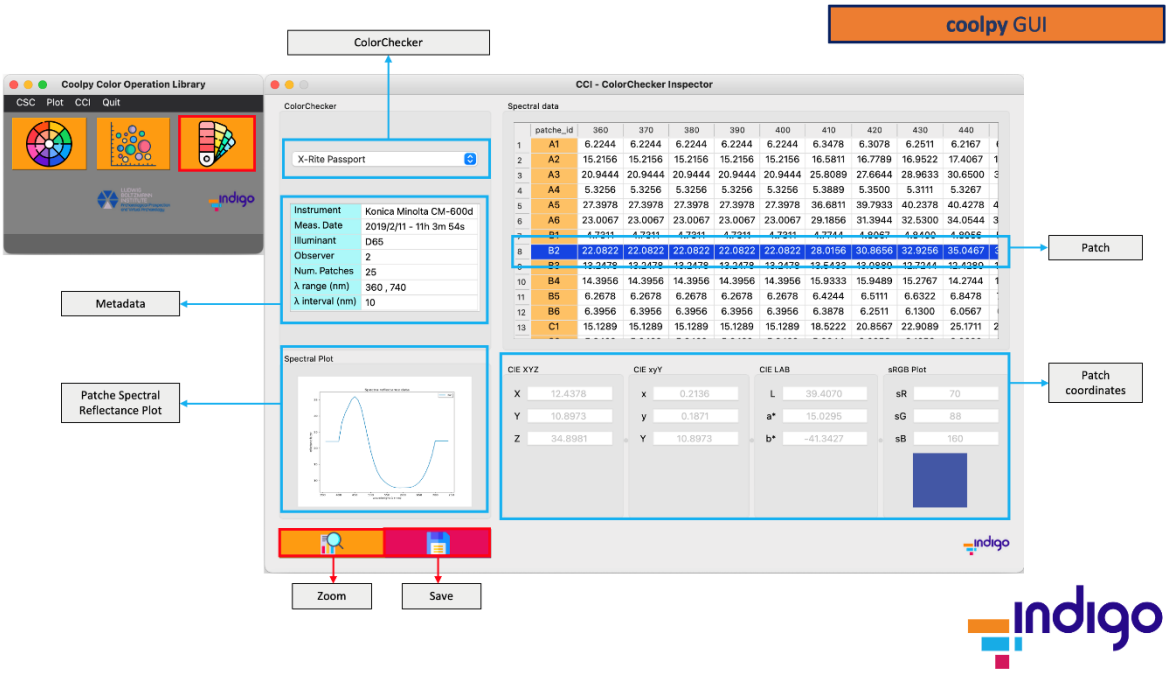

Fig. 60. One of the many analytical functions that coolpy will offer via its graphical user interface.

Appendix "Media Coverage 2021"

LBI ArchPro misc.

online

- https://www.sn.at/salzburg/chronik/archaeologen-spueren-einem-heiligen-nach-102068011
- https://www.fiuman.hr/tehnicki-fakultet-u-srpnju-postaje-centar-znanja-za-analizu-slike-i-racunalni-vid/
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- https://www.ostsee-zeitung.de/Vorpommern/Ruegen/Putbus-auf-Ruegen-Wird-das-Fuerstenschloss-wieder-aufgebaut
- https://www.ostsee-zeitung.de/Vorpommern/Ruegen/Start-in-Putbus-Greifswalder-Forscher-untersuchen-Herrenhaeuser-im-Ostseeraum
- https://tvheute.at/news/orf-universum-history-herbstwinter-highlights-2021--von-antoine-koepe-ueber-augustus-und-livia-die-reisen-des-jungen-jfk-durch-europa-uvw_-626149568
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- https://britishheritage.com/history/hidden-landscapes-stonehenge
- https://www.meinbezirk.at/tulln/c-lokales/donauschiff-danuvina-alacris_a4785059#gallery=null

print

- Archäologen spüren einem Heiligen nach (Salzburger Nachrichten, 7.4.2021)
- Der Donau Limes (Österreich Journal; S. 103-104; 12. Februar 2021)

Radio

- Radio-Interview Wolfgang Neubauer, Radio rtv (Slowakei), 8.5.2021: https://www.rtvs.sk/radio/archiv/1161/1561924

Piber Digital & exhibition

online

- https://science.apa.at/power-search/8724572602302691477
- https://kurier.at/wissen/wissenschaft/so-erobern-die-lipizzaner-jetzt-das-netz/401191894
- https://science.orf.at/stories/3204826/
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- https://www.wienerzeitung.at/nachrichten/wissen/geschichte/2093565-Die-Heimat-der-Lipizzaner-wird-digitalisiert.html
- https://www.krone.at/2345908
- https://www.kleinezeitung.at/steiermark/5938850/Gestuet-Piber_So-laeuft-der-virtuelle-Ritt-ueber-das-Lipizzanergestuet
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- https://www.meinbezirk.at/voitsberg/c-lokales/lipizzanergestuet-piber-mittels-drohne-vermessen_a4490252
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- https://www.meinbezirk.at/voitsberg/c-wirtschaft/das-modernste-museum-der-weststeiermark-plus-video_a4875085
- https://www.kleinezeitung.at/steiermark/weststeier/6018836/11-und-12-September_Das-Gestuet-Piber-laedt-zum-Fest-der-Lipizzaner

print

- Künftig auch virtueller Ritt über das Lipizzanergestüt (Kleine Zeitung, 18.02.2021)
- In Piber gibt es jährlich Sonderausstellungen (Kleine Zeitung, 20.02.2021, S.32)
- Lipizzaner digital (Kurier, 18.02.2021)
- Gestüt wird digital gesichert (TT Kompakt, S. 27, 19. Februar 2021)
- Die Heimat der Lipizzaner wird digitalisiert (Wiener Zeitung, S. 27, 20.2.2021)
- Digitales Gestüt für Lipizzaner (Die Presse, S. 36, 20.02.2021)
- Die Heimat der Lipizzaner ist digital dokumentiert (Salzburger Nachrichten, S. 7, 25.02.2021)
- Gestüt mit Drohne vermessen (Woche Steiermark, S. 18-19, 24.02.2021)
- Gestüt Piber lädt zum Jubiläum (Kleine Zeitung Weststeiermark, 13.08.2021)
- Ein Museum als Jubiläumsgeschenk (Kleine Zeitung, 12.09.2021)
- Neues Museum der Lipizzaner eröffnet (Kleine Zeitung Weststeiermark, 12.09.2021)
- Traumhafte Pferde beim Fest der Lipizzaner in Piber (Österreich Steiermark, 10.09.2021)
- Ein Museum der neuen Art (Woche Voitsberg, 15.09.2021)

Radio

- Ö3 Journal, 18.2.2021, Journal: Piber

TV

- Seitenblicke (ORF 2, 17.09.2021)
- Mayr Magazin (ORF 2, 17.09.2021)
- Servus am Abend (Servus TV, 13.09.2021)
- Steiermark Heute (ORF 2, 11.09.2021)

Kleinhadersdorf

online

- https://www.noen.at/mistelbach/kleinhadersdorf-fabrik-aus-der-steinzeit-ausgegraben-poysdorf-graeberfeld-wolfgang-neubauer-mahlsteine-archaeologen-johannes-wolfgang-neugebauer-ludwig-boltzmann-institut-print-290672842
- https://www.meinbezirk.at/mistelbach/c-lokales/erntezeit-fuer-archaeologen_a4868617

print

- Es ist Erntezeit für unsere Archäologen (Bezirksblätter NÖ/Mistelbach, 22.09.2021)
- Eine Fabrik der Steinzeit (NÖN Mistelbach, 15.09.2021)

Tieschen/Königsberg

online

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print

- Der Königsberg wird ein Archäologie-Hotspot (Kleine Zeitung, S. 28-29, 05.03.2021)
- Königsberg wird jetzt zum Forschungsgebiet (WOCHE Steiermark/Radkersburg; 10. März 2021, S.18)
- Der Königsberg und seine Geheimnisse (Kleine Zeitung, S. 26, 18.04.2021)
- Erfolgreicher Start auf dem Königsberg (Kleine Zeitung, 07.07.2021)
- https://www.tieschen.gv.at/fileadmin/user_upload/Gde-Ztg_Tieschen_1_2021.pdf
  („Forschung rund um den Königsberg"; „Universitätslehrgang bei uns in Tieschen")
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- https://www.tieschen.gv.at/fileadmin/user_upload/gemeindezeitung/Gde-Ztg_Tieschen_20S_18.10.21.pdf
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MAMUZ church

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- Dachgleichenfeier im MAMUZ (Bezirksblätter NÖ, 07./08.07. 2021)
- Bauen wie im 9. Jahrhundert (Kronen Zeitung, 19.09.2021)

Stonehenge Ausstellung – Herne, LWL

online

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