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1. Introduction

1.1 Motivation

Considering the massive threat of destruction and deterioration of buried cultural heritage and the need for efficient and reliable identification, documentation and interpretation methods, large-scale application of non-invasive archaeological prospection methods comprise a great potential. They are the most appropriate solution in order to provide archaeologists and planning authorities with the necessary spatial information for the protection and possible investigation of such threatened heritage at the appropriate scales: the archaeological site as well as the surrounding archaeological landscape. In order to advance the state of the art and focusing on future demands for non-invasive professional archaeological prospection, a consortium of European research institutes, heritage boards and public bodies supported by the Ludwig Boltzmann Gesellschaft (LBG)¹ established the Ludwig Boltzmann Institute for Archaeological Prospection and Virtual Archaeology (LBI ArchPro)² in 2010. The LBI ArchPro is an innovative research centre for the development and application of advanced non-destructive prospection methods. It combines advanced remote sensing methods, high-resolution near surface geophysics, sophisticated computer science, geomatics and archaeology. It is dedicated to the development of new and highly efficient technologies for non-invasive data capturing, data processing, virtual reality visualisation and the advancement of theory and methodology of archaeological prospection. An important aim is the publication and dissemination of new developments and results of the conducted research and of exemplary international large-scale case studies in professional circles as well as to the general public.

1.2 Mission statement

The mission of the LBI ArchPro, as currently supported by the LBG and a consortium of ten European institutions (constituting itself of academic and dedicated research institutes, museums, heritage boards, SMEs and governmental bodies), is to promote innovative and non-invasive archaeological prospection and digital documentation methods. The main motivation that has been

¹ <http://www.lbg.ac.at>

² <http://archpro.lbg.ac.at>

driving the LBI ArchPro approach so far, and which will push it beyond its limits in the future, lies in the societal necessity to develop efficient means for the reliable identification, documentation and interpretation of buried and still standing archaeological heritage, which is under serious threat from destruction and continuous deterioration.

The large-scale application of non-invasive high-resolution archaeological prospection methods and the subsequent exploration of the resulting huge 3D and 4D data sets by means of digital archaeology are the most appropriate solutions for future archaeology. The proposed innovative approach provides archaeologists and planning authorities with the necessary spatial information required for the protection and investigation of threatened buried and still standing heritage at the appropriate scales: the archaeological site as well as the surrounding archaeological landscape. The Valetta Convention (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 as important guideline and impetus for the advancement of future technologies and methods safeguarding and preserving our common cultural heritage.

The truly multi-disciplinary setup of the LBI ArchPro combines an internationally unique+ and unrivaled pool of resources and expertise. This approach integrates the scientific fields of remote sensing, geophysics, geomatics, computer sciences, and archaeological research. Thereby, the development of novel, universally applicable tools for the efficient non-destructive, high-resolution detection, visualization, spatio-temporal analysis, and integrative interpretation of our archaeological heritage becomes possible. The multi-scale strategy permits detailed archaeological investigations reaching from individual postholes to entire cultural landscapes.

The highly successful development of the LBI ArchPro so far has clearly shown the potential of the application of cutting-edge technology and integrated interpretation approaches to illuminate archaeological heritage by visualising unique and formerly unknown, otherwise invisible archaeological monuments and sites, contributing data and new information of great value to scientists, stakeholders as well as the general public alike.

1.3 Highlights 2019

- 100% confirmation of the Gjeltestad Viking ship discovery made by LBI ArchPro partner NIKU through excavation by Norway's Museum of Cultural History
- Successful extensive archaeological prospection surveys of Iron Age fortresses and central places in Denmark
- Good progress with innovative data visualisations
- Successful collaboration with the Austrian Armed Forces with regard to prospection on military training grounds
- Interpretation of the GPR data from the KGA Velm was confirmed in detail by excavation
- 10-years LBI ArchPro anniversary celebration with the international partners and scientific advisory board members

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:

- Data acquisition and processing (DAP)
- Data visualisation (VIS)
- Integrated data interpretation (INT)
- Underwater Prospection (UWP)
- Data management (DM)
- Data fusion (DF)
- Semiautomatic feature extraction (FEX)
- Reconstruction (REC)
- Simulation (SIM)
- Spatio-temporal reasoning (STR)

All research topics were interlinked to a large degree. They were broken down into tasks and assigned to respective task groups. As several tasks needed the skills of various staff members, dynamic teams were formed for direct and efficient interaction to solve the respective tasks in close collaboration involving both main staff and staff from the partner organizations. The research topics were flanked by five horizontal programme elements:

- Dissemination (DISS)
- Training and teaching (TRAIN)
- Case Studies (CS)

In the following, the progress made over the course of 2019 is described according to the defined research topics and lateral programme elements.

2. Data acquisition and processing (DAP)

The two domains *data acquisition* and *data processing*, including corresponding hardware and software development, are closely interlinked and have therefore been combined. In general, the main foci are on airborne and terrestrial LiDAR, image based modelling, magnetometry, ground-penetrating radar, and electro-magnetic induction for large-scale archaeological applications.

2.1 Geophysics

Over the past year a major overhaul of the MIRA II system was conducted. A new antenna box was purchased due to several hair cracks in the old one, which had caused considerable water penetration into the box and electronic components. The humidity had a detrimental effect on the quality of the GPR data. At the same time, the electromagnetically absorbing special foams in-between and around the individual transmitter and receiver antennae was renewed. A major data acquisition computer upgrade was performed by installing a new one TB SSD hard-drive and by updating the operating system to Windows 10. Furthermore, a special recovery program was installed for data rescue in the field, if necessary.

The steering rod system of MIRA I was renewed, which had become necessary after years of heavy use. Additionally, a track extension of the rear wheels of the Kubota tractor was mounted in order to gain greater stability while driving on sloping surfaces. The submerged research sonar boat AURORA was replaced with a new boat, the FREGGEL ÖLF, and equipped as survey boat (see section on Underwater prospection). Furthermore, a concept was developed to upgrade the experimental motorised Caesium gradiometer cart from 50 cm to 25 cm cross-line sensor spacing.

2.2 Extension of ApSoff 2.0

For the software for processing geomagnetic prospection data, ApMag, a method for modelling the susceptibility distribution of a 10cm thick layer under the arable layer was developed to estimate the size and location of possible archaeological structures more accurately. Furthermore, a method was developed to reconstruct near-surface magnetic dipole anomalies, to determine the depth and to estimate the size of the object.

For the software for processing georadar data, ApRadar, a new visualization method was implemented, which visualizes fracture zones in radar data, similar to the coherence processing in seismic data processing. Furthermore, the detection of faulty traces in radargrams was improved and an automatic method for testing and swap-back traces in Mira data, which are erroneously stored in adjacent channels, was implemented. ApRadar has been extended for further georadar antenna systems (MALÅ IGX 160) and can now generate position files from older, stacked out measurements, so that these data can be processed with the software tools with free positioning.

In spring 2019 two workshops on geophysical data processing with ApSoft were held. A three-day workshop for the partners Norsk Institutt for Kulturminneforskning and Vestfold og Telemark Flykeskommune in Oslo and a one-day workshop for the LBI ArchPro in Vienna.

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 perspective as well as a practical viewpoint. At the LBI ArchPro, both aspects of image-based modelling are continuously researched and improved.

Automated defocus mapping

From a technical side, the possibility of automated image masking was explored. Acquiring photographs as input for an image-based modelling pipeline is less trivial than often assumed. Photographs should be correctly exposed, cover the subject sufficiently from all possible angles, have the required spatial resolution, be devoid of any motion blur, exhibit accurate focus and feature an adequate depth of field. The last four characteristics all determine the ‘sharpness’ of an image and the photogrammetric, computer vision and hybrid photogrammetric computer vision communities assume that the object to be modelled is depicted ‘acceptably’ sharp throughout the whole image collection. Although none of these three fields has ever properly quantified ‘acceptably sharp’, it is more or less standard practice to mask those image portions that appear to be unsharp due to the limited depth of field around the plane of focus (whether this means blurry object parts or completely out-of-focus backgrounds). A MATLAB toolbox was created to assess how well- or ill-suited defocus estimating algorithms are for automatically masking a series of photographs, since this could speed up modelling pipelines with many hundreds or thousands of photographs.

Many defocus blur estimation methods claim a good trade-off between accuracy and runtime. However, these claims often go unchallenged and are usually based on an unrealistic image set. This research revealed that most state-of-the-art algorithms still face many challenges. However, at least one method showed a level of accuracy and robustness which could render it useful for future application (see Fig. 2.1).

Müstair (Switzerland)

One of the rooms in the monastery Saint John at Müstair is the Norpertsaal (Fig. 2.2), characterised by two large frescoes that depict a Christian scene. Of these two Romanesque frescoes, one is restored (Fresco A), while the other needs a system to monitor its deterioration (Fresco B). On the 15th and 16th of October 2019, a part of fresco B was photographed to document its surface three-dimensionally (3D). The overall idea was to collect data and experience that could ideally lead to a better image-based monitoring system for this fresco. To enable the detection of sub-millimetre changes, all images were acquired with a ground-sampling distance of 50 μm , which is sufficient to obtain a 3D model in which surface details (and thus changes) of 0.1 mm are detectable.



Figure 2.1: Comparison of the automatically generated binary image masks with a reference mask across four image sets. The masks were generated after thresholding a full defocus map that was computed by three different methods (mentioned on the left). The average running time for one type of image is displayed for every method. Finally, black means masked, white means not masked.

Within Agisoft Metashape Professional 1.6.0, a very detailed 3D surface model (in the form of a triangular mesh) was generated. A 1 cm-long section through the undecimated version of this 3D mesh is depicted in Figure 2.3. The vertical range of this section runs from 0 mm to 0.5 mm, indicating the amount of digitally encoded surface detail. This result shows that an image-based monitoring system to quantify a fresco's topographic surface degradation is achievable. Ideally, a fixed structure is erected in front of the fresco. This structure would support a robotically-steered camera that can photograph the whole surface in a controlled and automated way.

2.4 Terrestrial and airborne laser scanning

Recent technological and methodological development increases the range of applicability and combinability of various methods for 3D data recording. The combination of various ground and airborne based techniques enables high resolution and time and cost effective documentation of different settings and locations. During the last year, new equipment, survey strategies, data acquisition routines, data processing and analysis were tested, evaluated and applied.

TLS

Riegl LMS developed a new series of terrestrial Laserscanners, named VZ i-series. These improved Scanners rely on the VZ-platform but provide additional capabilities and features. The most relevant is the possibility to record and align 3D data without GNSS or retro targets. When the scanner is moved within 20 to 30 seconds from one position to the next, the system can calculate the trajectory and hence defines its new position. Scanning is also sped up by a factor of five, which fastens and simplifies the survey extremely. The LBI ArchPro had access to a VZ400i and a VZ2000i to test the new setup during surveys in the Erzgebirge (Germany, Copper mine) and Gars (Austria). This experience was successfully integrated into later surveys in Svalbard (Norway) and Chachapoyas (Peru), where a VZ2000i and a VZ2000 were operated with the partner NIKU and Brown University of Boston/ USA.



Figure 2.2: The Norpertsaal of the St. John Monastery features two frescoes. The image acquisition test area is indicated.

At the same time the institute's own scanner (VZ400) was technically rigged to enable the use of GNSS RTK. Javad Triumph receivers can be used in base-rover-configuration to guarantee a positioning accuracy of 1 to 2cm. The setup was tested and worked properly. Though this setup might be outdated by the new i-series it is still fundamental for accurate positioning in open and wide areas where no retro targets can be used or are not available.

ALS

TLS provides excellent high-resolution data of visible objects at close and mid-range. Objects like roofs, which are not in the physical range of the scanner or are simply not accessible need to be documented from an elevated position. Vegetation can be filtered more easily under a strict survey geometry. For both purposes ALS is the right tool. Riegl LMS provides a UAV (Ricopter) capable of lifting and operating their new VUX Laserscanner. A big advantage compared to aircraft operated ALS is the possibility to collect data at lower operating altitude. This results in a denser point cloud and the chance to collect data from the faces of upstanding features in greater detail.

The combination of TLS and UAV based ALS was tested at the castle of Gars and the medieval

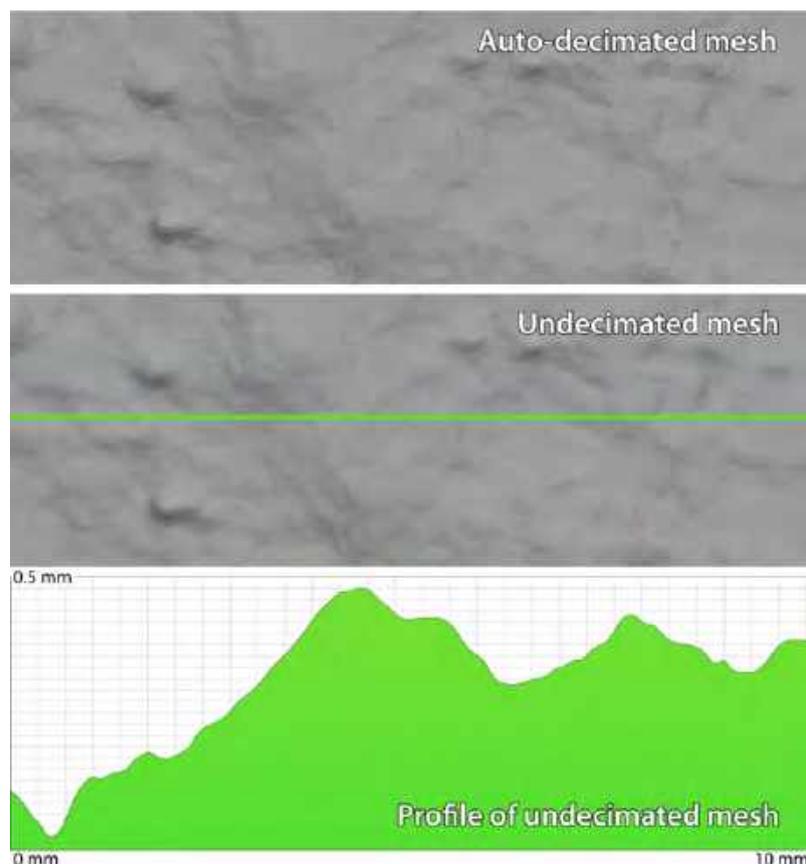


Figure 2.3: This image depicts a 1 cm long profile through a part of the fresco's undecimated mesh.

fortified settlement Thunau. Riegl LMS introduced the functionality of the Ricopter and VUX scanner to our team. A survey strategy was discussed and realized together.

UAV based IBM

Several legal issues made the use of the institute's own UAVs impossible during the last years. Therefore a small drone (DJI Mavic Pro) was acquired. The drone was tested and operated successfully at many different locations (Svalbard, Schwarzenbach, Gars, Altstätten). It proved to be a perfect tool for collecting basic airborne IBM data for the recording and documentation of monumental sites (castles, ruins, landscapes) and excavations (Eisengraberamt, Schwarzenbach, both Austria). Besides these pure scientific tasks, disseminative aspects are also covered. Image and video footage are recorded easily and is an important part of the LBI ArchPro dissemination strategy.

The drone also proved to be a very handy tool for collecting snapshots at archaeological prospection surveys, documenting the environmental conditions or to simply obtain an overview from the bird's eye perspective.

Survey strategies

The application of this new equipment and recent development of processing software – namely RiscanPro 2.8 – have an impact on the survey strategies. Besides the capabilities of the new i-series of Riegl laserscanners, which make the use of retro targets mostly unnecessary, improved algorithms for the estimation of single scan positions enable a fast and accurate registration of scan projects. This registration procedure aligns hundreds of scan positions within a short period of time. E.g.:



Figure 2.4: Javad Triumph GNSS receiver mounted on Riegl LMS VZ400.

The alignment of 340 positions recorded at Kuelap in Peru took only 25 to 30 minutes. This enables fast controlling of the collected data, which is an enormous advantage especially in remote areas. For this registration procedure an initial position of the scanner has to be provided. As the position accuracy has to be roughly below 10 m, uncorrected GNSS data provided by the internal GNSS receiver is sufficient. VZ i-series scanners even work without GNSS connection as the system can calculate the trajectory of the scanner being moved by the operator in using data from the internal IMU and orientation sensors. For an accurate georeferencing at an accuracy of 1 to 3 cm, control points (retro targets) must still be used. In this case only a few core positions are necessary, i.e. placing a couple of reflectors at 1 or more positions of the whole project.

Based on these new survey strategies more time effective surveys were already carried out in Staats (Austria), Svalbard (Norway), Altstätten (Switzerland) and various sites in Peru.

Combination of datasets

A main task of the LBI ArchPro is the combination and integrated interpretation of various datasets. In the field of 3D recording a combination of ALS, TLS and IBM is necessary in most survey scenarios. Among the most challenging projects demanding this combination are the surveys in Svalbard run by NIKU, Kuelap in Peru and Gars in Austria. For the combination of TLS and IBM the software RealityCapture (<https://www.capturingreality.com/>) turned out to provide excellent methodologies and visualization.

In order to go below the surface, the implementation of GPR data into respective models is the next logical step of intergrated data visualization and interpretation. This was done for the first time



Figure 2.5: Excavation Eisengraberamt – DJI Mavic Pro.

during the investigations at the castle Rosenberg/ Austria, that already illustrated the benefits of this approach, and was extensively studied throughout the survey in Staatz/ Austria.

Data processing

RiscanPro 2.8 provides new algorithms and procedures to register scan projects more efficiently. Scan registration 2 enables a fast alignment of all scan positions, which have an initial positioning accuracy of about 10m and below. This is gained either in using uncorrected internal GNSS receiver data (all VZ series) or trajectory calculation (VZ i-series). For accurate georeferencing (1 to 3 cm) control points are still needed for at least one scan position. It proved to be useful to use at least two or three of these core positions per project to guarantee a stable geometry. During multistation adjustment these control points are treated as usual reflectors for georeferencing the whole project. All scan positions are shifted in a block according to the global coordinates defined by the control points. The calculated offset between geodetically measured control points and scanned reflectors can be visualized for better control. A workflow menu is guiding through the procedure. This new processing workflow was tested prior to the survey at Svalbard, where it was applied successfully.

Data analysis

Throughout the application of IBM, ALS and TLS DTS and DTM are generated, which can be used for further spatial and topographical analysis. Another aspect of analysis is dealing with the extraction of objects and features from these datasets. When combining TLS and GPR data it is useful to interpret the TLS data regarding different surface structures. E.g.: During the survey in Staatz it was necessary to indicate changes of the road pavement, manhole covers, etc. For the interpretation of TLS data, the development and testing for 3D analysis and drawing tools is a demanding factor. So far, first routines have been tested on the dataset of Altstätten.

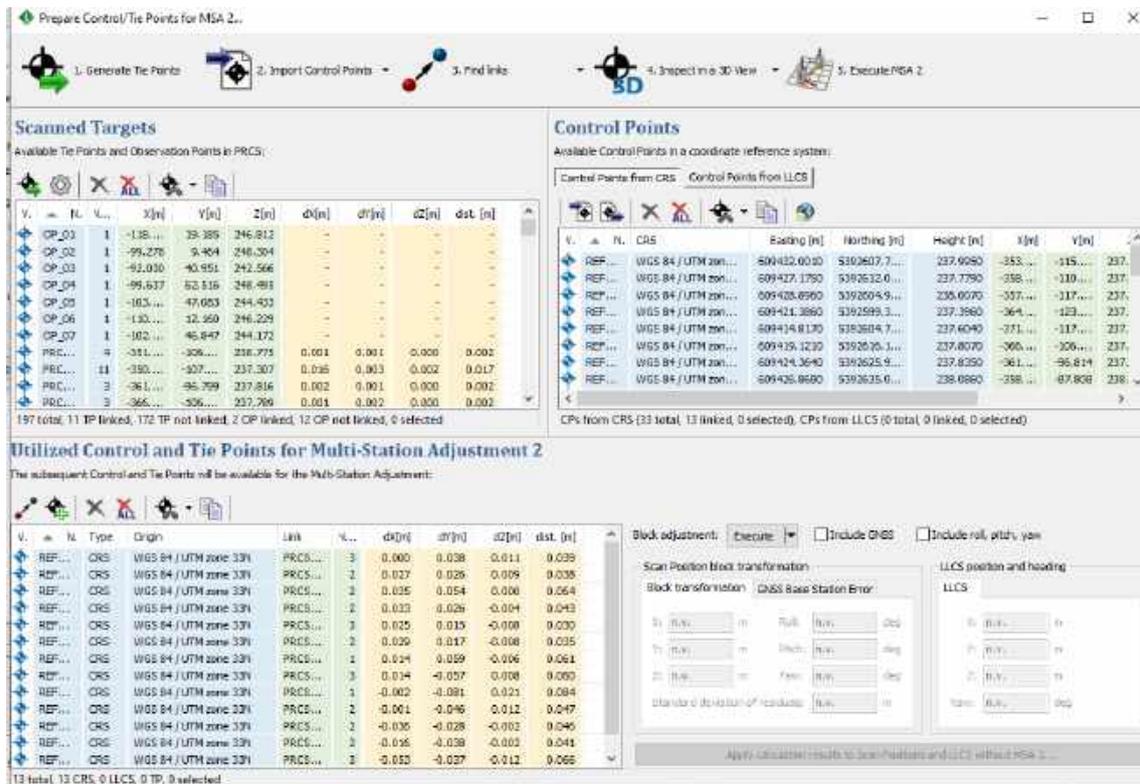


Figure 2.6: MSA workflow RiscanPro 2.8.

3. Data visualisation (VIS)

As comprehensive data visualization is crucial for the perception of relevant archaeological information contained in archaeological prospection data sets, this topic is highly relevant for correct archaeological interpretation of the prospection data and the dissemination of the generated results. A special focus is placed on GIS-based visualization of prospection data, dynamic visualization of 3D volume data and novel 3D visualizations of prospection data.

3.1 3D GPR data visualisation

Visualisation techniques tailored to the nature of the datasets at hand are a key requirement for optimally exploiting their archaeologically relevant information. Data interpretation requires both, imagination and a broad domain understanding. Since all, GPR, archaeological structures, and the way human observers understand them are three-dimensional, it is worthwhile to investigate the possibilities of 3D visualisation with the goal to increase interpretation quality and efficiency.

Therefore, LBI ArchPro has intensified the collaboration with LBI CFI in Graz in 2019. Their visualisation approach for heterogeneous forensic 3D data has been developed further, to support archaeological 3D data, including 3D volumes (GPR), 3D point clouds (LiDAR), 3D surfaces (photogrammetry, virtual reconstructions/CAD) and 2D images.

3D volume visualisation of GPR data sets already creates a better visual depiction of the archaeological 3D structures contained than a 2D slice based approach. In addition, the flexibility of the visualisation algorithm supports the conjoint visualisation of GPR data with any other dataset involved, including local control over visualisation parameters. Practical applications include the comparison of manual interpretations and the underlying GPR datasets as well as excavation evidence 3D models of structures like holes and ditches.

For the first time it was possible to generate 3D visualisations combining 3D prospection data, their manual interpretation, 3D models documenting the excavation, and complementary CAD models, leading to unprecedented possibilities to document, analyse and disseminate archaeological sites and procedures in a comprehensive and easily understandable way (see Fig. 3.1–3.2).

To open up even more possibilities for both, experts and visitors, the visualisation software has been extended to support virtual reality hardware. The first prototype supports the immersive



Figure 3.1: Integrated 3D visualisation of a Neolithic house including GPR prospection data and excavation photogrammetry models.



Figure 3.2: Visualisation of a Roman forum based on filtered GPR data, polyhedral interpretation, reconstructed 3D building model and terrain model of the area.

exploration of full-scale GPR datasets and interpretations. Advanced interaction including the possibility to perform interpretation tasks in virtual environments will be investigated.

3.2 Etruscan tombs at the Necropolis of Banditaccia, Cerveteri

The Etruscan city of Cerveteri was, from the ninth century BC onwards until its incorporation into the Roman political system, one of the most important settlements in the Mediterranean world. The city was founded on a plateau entirely surrounded by necropolises. Our research project was focused on a burial mound located north of the famous Necropolis of Banditaccia. The integrated analysis of vegetation marks, ERT and high resolution GPR data bared the opportunity to investigate the Etruscan necropolises in highest detail and revealed perfect information on the preservation status of the buried archaeology. Combining the information derived from the multi-method survey it became clear that the strong GPR amplitudes weren't caused by stone but showed cavities representing the vault of individual burial chambers. Using 3D point-cloud visualisations of IBM and GPR data, it was possible to map and model the vault of the burial chambers to such a detail to understand even the internal setting. The additional calculation of a 3D point-cloud visualization revealed the inherent data loss of the time-consuming interpretative mapping using 2D depth slices. The site of Cerveteri proved once more the ability to visualise archaeological details of still buried remains even in challenging geological conditions.

3.3 Sigmoid mapping

TAIFU offers many options for data visualisation (such as perceptually-uniform colour maps). One of those options is a sigmoid-based mapping of magnetic values. Magnetic values are often stored as floating-point numbers to encode the extended range of magnetic data values. However, for ease

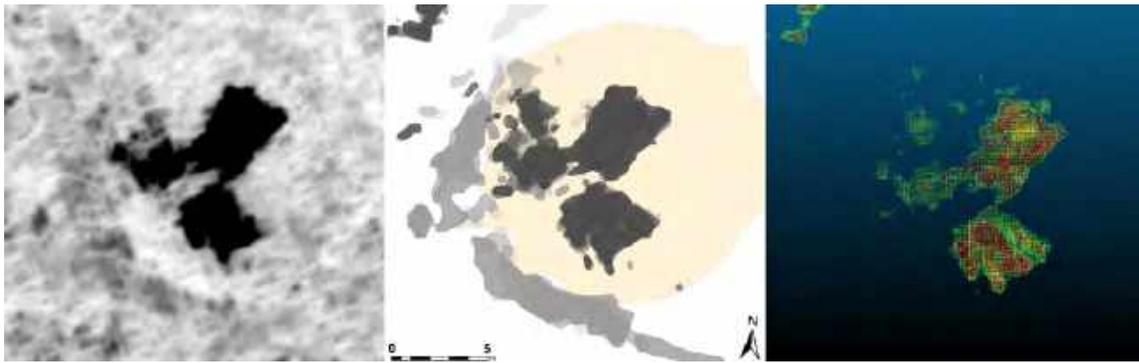


Figure 3.3: (left) GPR depth slice 40 to 250 cm, (centre) interpretative mapping of GPR data (grey = path, black = burial chamber, ochre = tumuli), (right) 3D point-cloud calculated from GPR dataset.

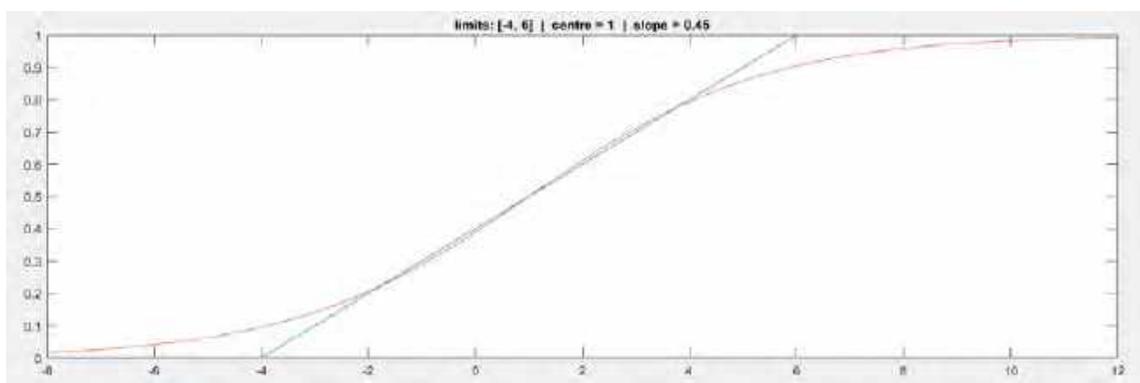


Figure 3.4: The sigmoid function with centre value 1 and slope 0.45 versus a linear mapping between -4 nT and 6 nT.

of use in GIS, the values of these images have to be ‘mapped’ to a [0, 1] range. Usually, this is done with a linear approach, in which a starting value is set to 0 and an ending value to 1 (e.g. from -4 nT to +6 nT). Everything outside this range is mapped to either 0 (values < -4 nT) or 1 (values > 6 nT). Afterwards, all these values are scaled by 255 (for an 8-bit image) or by 65535 to produce a 16-bit integer image.

The newly proposed mapping method uses the sigmoid function, a mathematical function having a characteristic S-shaped curve. By varying the centre value and the slope of the sigmoid function, she can approximate the central portion of a linear mapping function very well (see Fig. 3.4).

The major difference lies in the way that very small or very large values are treated. There is no sharp cut-off as with the linear mapping function, but the sigmoid smoothly asymptotes towards infinity. This makes it possible to map also smaller (e.g. -nT) and bigger (e.g. +12 nT) magnetic values to the [0, 1] range, thereby producing an 8-bit or 16-bit integer image which retains some image details that would otherwise get lost with the linear mapping method (Fig. 3.5).

3.4 GIS development/ArchaeoAnalyst

The ArchaeoAnalyst is a toolbox for ArcMap 10.2 and 10.3 developed by the LBI ArchPro. Since the product versions of ArcMap 10.2 and 10.3 have officially been retired by Esri, the team of the LBI ArchPro has been enabled to use ArcGIS Pro, which was first released in 2016 and has

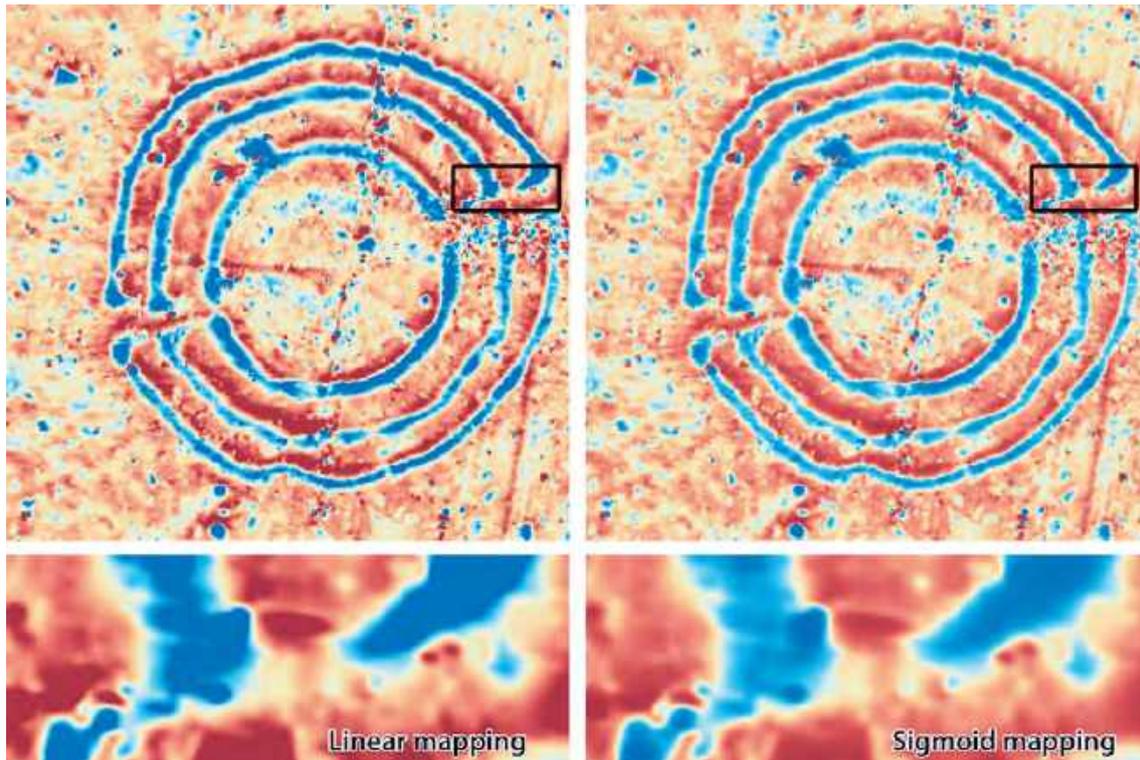


Figure 3.5: Linear (left column) versus sigmoid mapping (right column) on a magnetogram. The data have been colour-coded using a diverging, perceptually uniform colourmap (also implemented in TAIFU). The upper row shows that the overall contrast of the image stays almost invariant, while the lower row insets illustrate how the sigmoid mapping prevents saturation in the lower and higher nanotesla range.



Figure 3.6: The ArchaeoAnalyst toolbox added in the menu of ArcMap 10.2 and the ArchaeoAnalyst menu bar with the GPR depth slider and the Base Height Slider.

been continuously updated since then. It would be appropriate also to upgrade the ArchaeoAnalyst toolbox, which requires the first analysis of all the features included in the software.

The evaluation led to a report of the features included in ArchaeoAnalyst, including an assessment of all functions. The second step contained a best practice workflow for a GIS project created and used by the LBI ArchPro, to estimate the usefulness of the included functions in the newest version of ArchaeoAnalyst. The best practice workflow also contains a part of data handling and the folder as well as the data structure (Fig. 3.7). The next step will be to evaluate the functions of the software program ArcGIS Pro according to the best practice workflow. Then the ArchaeoAnalyst can be adjusted accordingly.

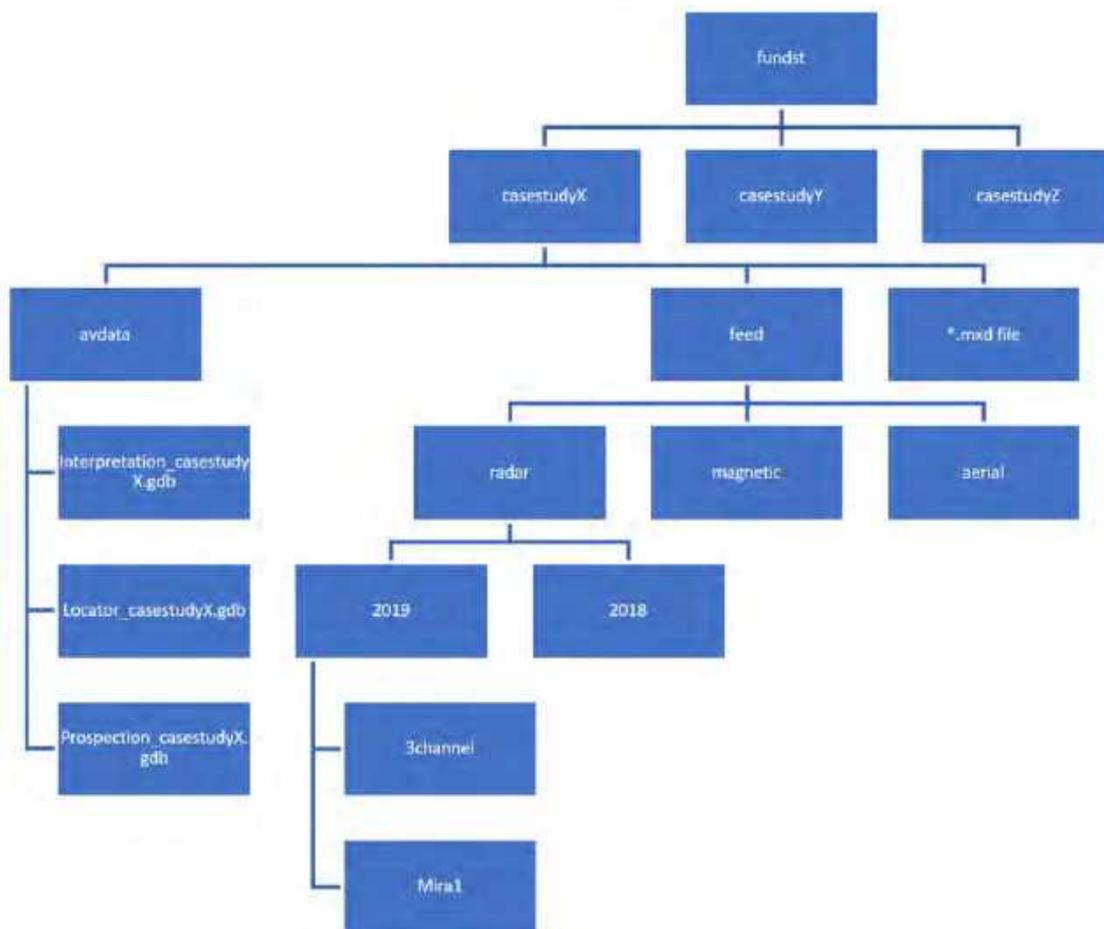


Figure 3.7: Diagram of the actual folder structure regarding the data interpretation with ArcMap at the LBI ArchPro.

4. Integrated data interpretation (INT)

Only the integration of the wide spectrum of non-invasive prospection methods will allow achieving a maximum of qualitative and quantitative information on buried archaeology. Our idea of integration is different from the current practice: Integration goes beyond a mere application of multiple techniques, where interpretations derived from different methods are added up in a general narrative or map. We intend to integrate all respective prospection data within our *ArchaeoAnalyst* GIS extension and to work on specific integrations by combined processing and visualization in 2D and 3D for an easier perception of archaeologically relevant anomalies within the combined data sets.

4.1 Flavia Solva

The interpretation of the GPR data obtained in the Roman city of Flavia Solva has so far concentrated on the area of the large bathing complex. In addition, however, a larger area was measured using high-resolution ground penetrating radar (MIRA). These data were interpreted in detail in 2019. The interpretation process revealed architectural structures such as floors, hypocausts or heating channels within clearly recognizable buildings, as well as road surfaces and water pipes underneath. Through the interpretation of the different depth-slices generated from our GPR data, several settlement areas (insulae) of the Roman city centre could now be analysed in detail and, thus, a regularly built settlement structure was revealed.

4.2 Interpretation of the prospection data from the Etruscan town of Vulci

The Etruscan town of Vulci is one of the few remaining opportunities to explore a largely untouched settlement centre of the ancient Mediterranean high culture. The antique central place was once strongly fortified and only accessible through massive city gates. But the former splendour is now buried under dry cattle and horse pastures. In summer 2018, a representative part of the city centre could be explored in detail with our ground penetrating radar systems. The data shows clearly that the former Etruscan metropolis was intensively used even in Roman times and the Etruscan buildings were transformed into pompous Roman town villas. Through the detailed analysis and



Figure 4.1: The orthogonal city layout of Flavia Solva was revealed by the combination of multiple prospection datasets.



Figure 4.2: Integrated interpretation of excavation and geophysical prospection data at the Roman town of Flavia Solva.



Figure 4.3: Interpretative mapping of the GPR data in the centre of the Etruscan town of Vulci.

archaeological interpretation of the GPR data, this building development is clearly visible and corresponds to the conclusions obtained from several decades of destructive excavations.

4.3 The Neolithic ring ditch system of Velm – prospection and excavation

The phenomenon of the Middle Neolithic ‘Kreisgrabenanlagen’ has always been a main research focus of the LBI ArchPro. In the past few years, a multi-method approach for the investigation of the KGA Velm (aerial photo, LIDAR, magnetometry, GPR) has already led to significant conclusions about the structure. By integration of the individual interpretations it became possible to improve the knowledge on the structure to a level of detail addressing individual post settings.

In summer 2019, the digital documentation of a research excavation carried out by the LBI ArchPro and the University of Vienna generated a new set of data, which again led to a significant improvement in the understanding of the site. This example made it nicely possible to make a statement on the position accuracy of our non-destructive methods and to draw a detailed comparison with the calculated depth of the corresponding GPR data.

Therefore, the digitised surfaces of the excavation were integrated into a new visualisation software, to permit a ‘direct’ comparison between the two data sets (GPR vs. excavation), and to evaluate their individual accuracy. It was thus possible to identify even structures which were not recognised during the manual excavation.

4.4 Montlingerberg

In autumn 2019, the hilltop of the Montlingerberg was resurveyed with the motorised multi-channel MIRA I GPR system in another field campaign. In 2019, the soil conditions were much dryer, and therefore, a direct comparison of the same area with different humidity situations could be made. A direct comparison of the GPR data from 2017 and 2019 showed two striking differences. The first one was the presence of animal burrows in the data from 2019. The second difference was the probable wall structure, which enclosed the Bronze Age settlement and which was better visible in



Figure 4.4: Digitised surface of a large multi-phase pit at the KGA Velm.

the data from 2017. Otherwise, the extent and location, as well as the appearance of bedrock, was almost the same in both datasets.

The next step will be a topographical correction of the raster data and an interpretation of the GPR raster data to define potential building layouts of the Bronze Age settlement. Another important aspect of this project is the constant monitoring of the site over time, which would be desirable for archaeological sites in general.

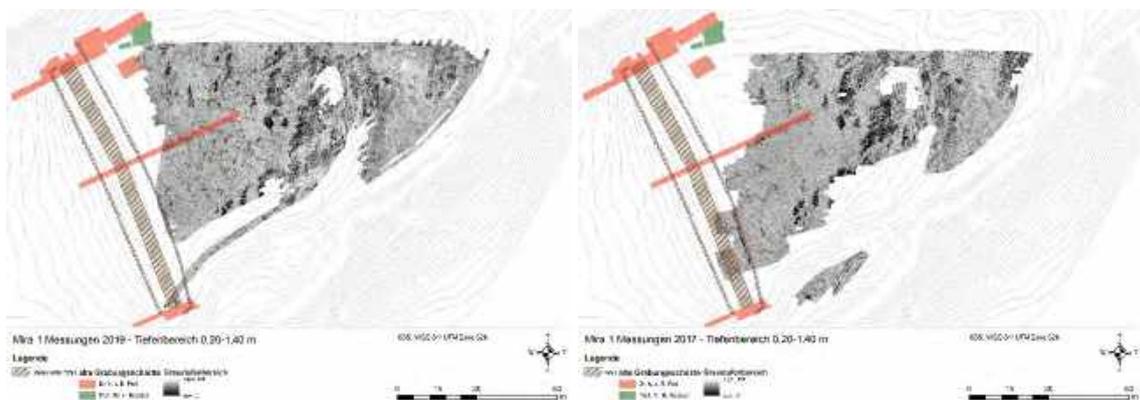


Figure 4.5: Montlingerberg: Left: GPR measurement from 2019 – depth slice from 0.20 to 0.10 m. Right: GPR measurement from 2017 – depth slice from 0.20 to 1.40 m.

4.5 Müstair – St. John Abbey

The Abbey of St. John is still an active Benedictine convent of nuns in the eastern part of Switzerland in the canton of Graubünden these days. The entire monastery building complex became a UNESCO World Heritage Site in 1983 due to the remarkable Carolingian and Romanesque frescoes. The Abbey of St. John in Müstair is one of the most comprehensive Medieval archaeology projects in Switzerland.

In autumn 2019, the LBI ArchPro conducted a GPR case study surveying the surrounding area of the Abbey, and an IGM test for high-resolution monitoring of frescoes. The aim was to get an understanding of environmental events as well as locate past human activities. The GPR images provide a glimpse into the history of the Abbey and its surrounding landscape. The geological structures are formed and also interfered by the formation of a small stream flowing down the mountains, possibly with smelting water. It even forms a small pond on the way down the slope, which was eventually crossed by a small road. The road has a length of around 150 m in an east-west orientation and varying width of 3.60 m and 5.50 m. The road crosses over a potential wall-like structure which follows the orientation and dimension of the buildings of the Abbey and could have been an extension of the monastery garden. At the western wall of the cemetery of the Abbey, around 40 graves arranged side by side were detected. The average dimensions of the burial pits are 2.6×1.20 m and the burial itself has the average dimensions of 1.80×0.80 m, starting to be visible in the data at a depth of around one metre.

The GPR data was interpreted in 10 cm depth-slices, therefore allowing a 3D view of the entire situation around the eastern area of the Abbey St. John (Switzerland). This approach of the data interpretation paints a more coherent picture of the archaeological relevant structures as well as the geological, hydrographical and modern formations.

Especially the geological interpretation of the data provides important information on the landscape. The different intensity of the reflecting deposits (Fig. 4.6) makes it possible to distinguish between different parts of the underground, such as paleosol (light brown), sandbanks of the river (dark brown), and accumulations at the shore (dark grey).

Adding the absorbing structures (Fig. 4.7) creates a more complex image of the stream (dark blue) which once flowed down the mountain, creating different meandering ways downward and also different extensions of the stream. Also, a small pond (light blue) was formed at a natural terrace.

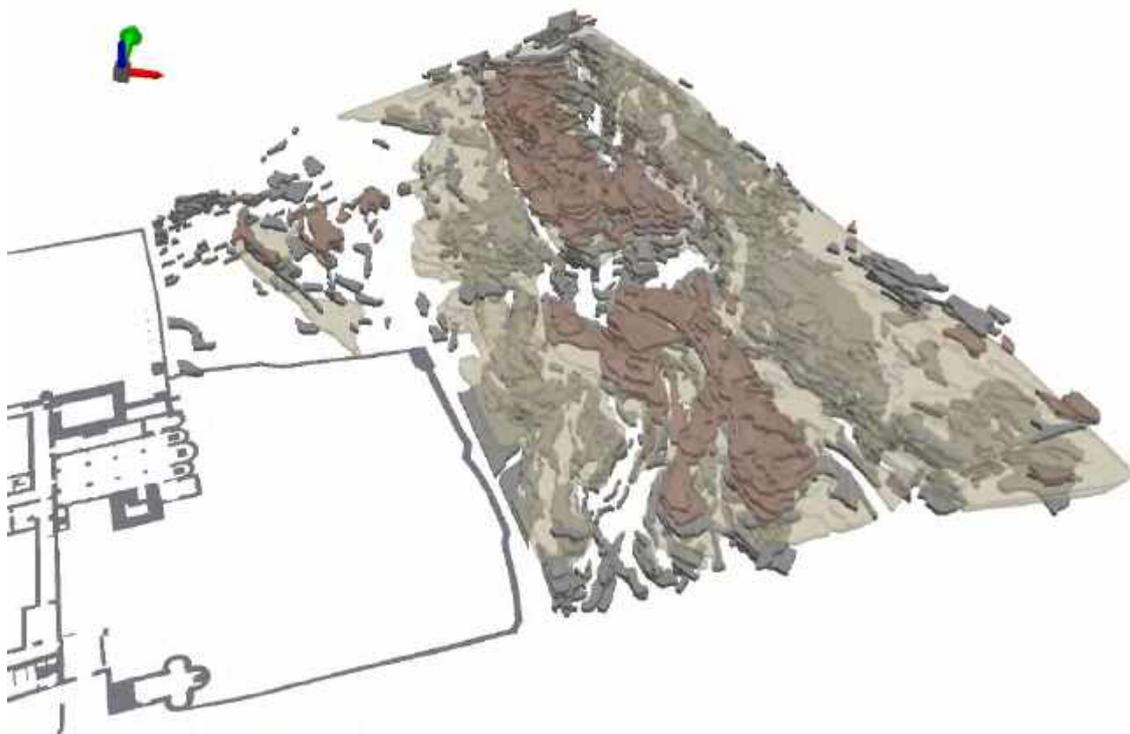


Figure 4.6: Paleosol of the western area of St. John's Abbey in 3D view.

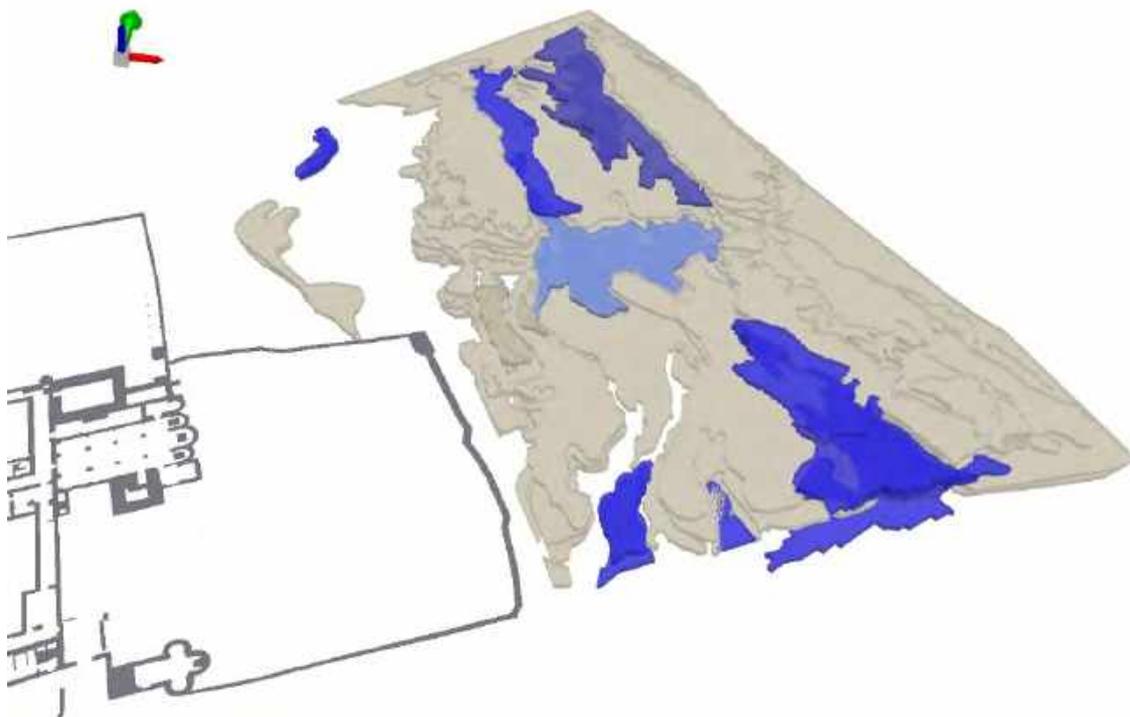


Figure 4.7: Direction of the possible stream (dark blue) with a small lake (light blue) in 3D view.

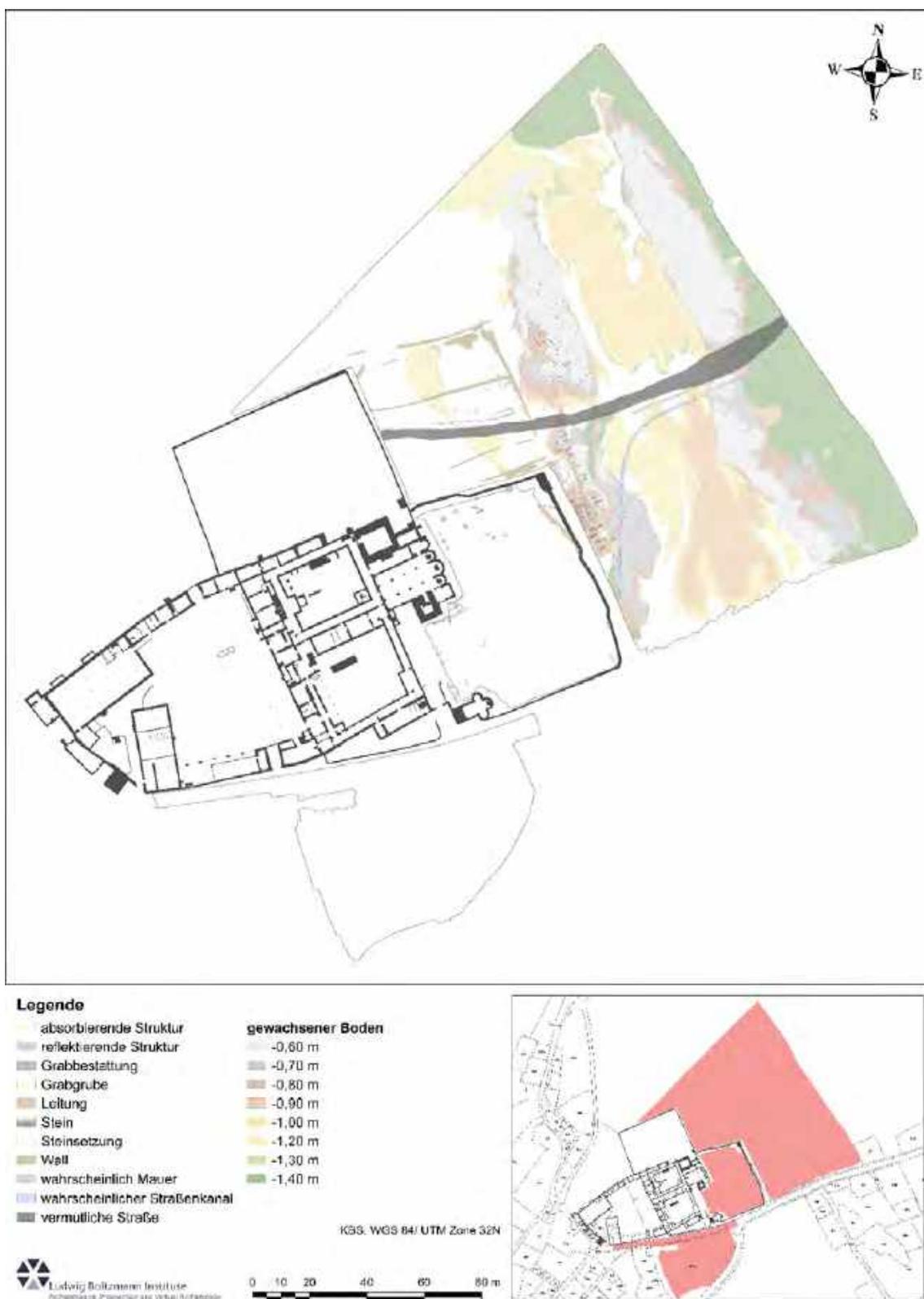


Figure 4.8: Archaeological interpretation of the prospection data from Müstair with paleosol in the background.

5. Underwater prospection (UWP)

A logical extension to the large-scale archaeological prospection of entire landscapes is the inclusion of wetlands and underwater archaeological landscapes. Using remote sensing methods in form of acoustic measurement methods (e.g. side scan sonar, multi-beam sonar, sub-bottom profiler) but as well underwater magnetometers or GPR operated from the water surface, or from submersible rovers on or near the seafloor, it becomes possible to map archaeological heritage buried underwater or in the sediments of lakes, rivers and maritime environments.

5.1 Sonar boat

In February 2019, a replacement survey boat named *Freggel Ölf* was purchased and collected in northern Germany. The boat is a *Buster XXL Cabin* built in 2011 with a 115 HP outboard engine. This boat type is the follow-up model of the first survey boat, which was a *Buster XXL AWC* that had been built in 2006. The old boat including the 150 HP Yamaha outboard engine could be sold without financial loss. The *Buster XXL Cabin* model is currently used by at least three commercial hydrographic companies for professional multi-beam sonar surveys.

The sonar mount was adapted to the bow-shape of the new boat, which in contrast to the closed bow section of the first boat is open. The boat trailer was modified in order to permit full deployment of the sonar mount without the cumbersome need for craning of the boat from the trailer. Thus, it is possible to level and calibrate the entire sonar system, consisting of the sonar sensor, the dual-head RTK-GNSS antenna system and the inertial measurement unit, while the boat remains on the trailer. A new power unit and workstation for sonar data acquisition were installed on the survey boat. The multi-beam sonar system was installed and an elegant cable routing was found through the hull leading from the computer rack in the cabin to the bow of the boat. The system calibration was performed with online support of MacArtney Germany. Thus, apart final adjustments to the system calibration that only will be possible on the water after relaunch, the high-resolution underwater prospection system is again ready for operation.

On invitation by the organisers of the conference *Dreiländertagung OVG – DGPF – SGPF 2019* held in February 2019 at the University of Natural Resources and Life Sciences in Vienna, the project *ArchPro Upper Austrian Lake Dwellings* and its preliminary results was presented and



Figure 5.1: The new survey boat *Freggel Ölf* with the sonar mount installed such that the sonar head can be deployed into measurements position with the boat on the trailer, for ease of sensor calibration.

received praise from Martin Wessels, head of the impressive, in scope comparable *Tiefenschärfe Bodensee* project.

In the framework of a course on Limnogeology of the University of Innsbruck, organised by Michael Strasser, the new high-resolution bathymetry of Lake Mondsee was presented. Over the course of one week in September 2019, the participants used the new bathymetric data to sample underwater structures of interest with cores. The massive underwater landslide discovered by the multi-beam sonar survey could be dated to the 1950ies. This structure appears to be related to motorway construction activities: it is believed that the dumping of gravel in the lake has mobilised a considerable amount of mud that resulted in the observed mudslide structure.

The so far acquired multi-beam sonar data of Lake Mondsee and derived bathymetric models and maps were delivered to the Department for Geoinformation, Survey and Remote Sensing of the province of Upper Austria, which is a project partner.

Otto Cichocki of the Vienna Institute for Archaeological Science provided a StarFish 990 kHz side-scan sonar sensor for high-resolution underwater imaging. This high frequency sonar head is able to provide images of the lake bottom with only $0.3 \times 0.3^\circ$ beam opening, and can be deployed as tow-fish or pole-mounted. It was tested in Lake Mondsee and in the new Danube in fix pole configuration on a small water craft with an RTK-GNSS receiver situated directly above the sonar head. The wreck of a *Citroën Traction Avant* vintage car that had been discovered during the multi-beam sonar survey in approximately eight metres depth near Union Yacht Club Mondsee was mapped with the side-scan sonar, demonstrating its high imaging resolution and a great level of detail (Fig. 5.3). For data visualisation the *SonarTRX Pro* software solution was used.

In 2019, with technical support of the LBI ArchPro, partner ZAMG acquired a remotely operated underwater vehicle (ROV) equipped with a 4K UHD camera, lights and a small gripper. This *BlueROV2* has been especially adapted for operation down to 200 m water depth and is fitted with an umbilical cord of 300 m length in order to permit the visual inspection of structures of

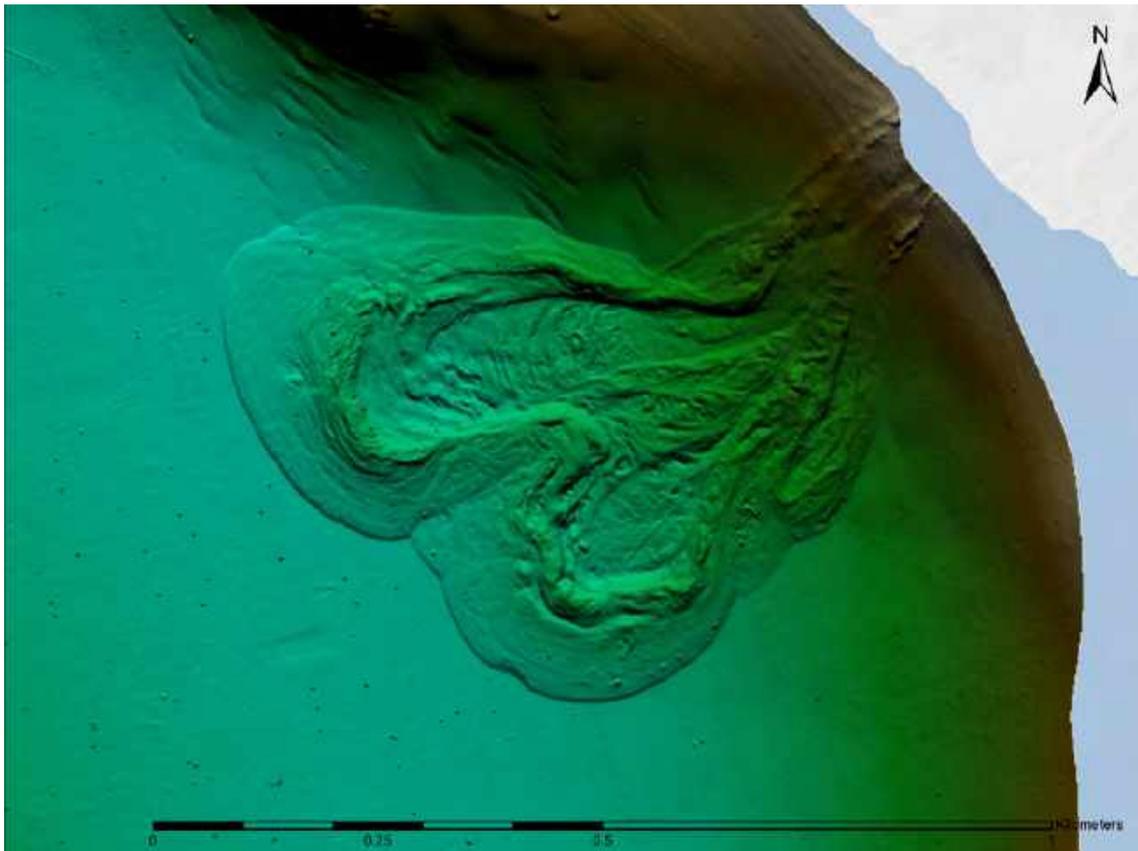


Figure 5.2: Bathymetry of Lake Mondsee showing the substantial mudslide that has been dated to the 1950ies.

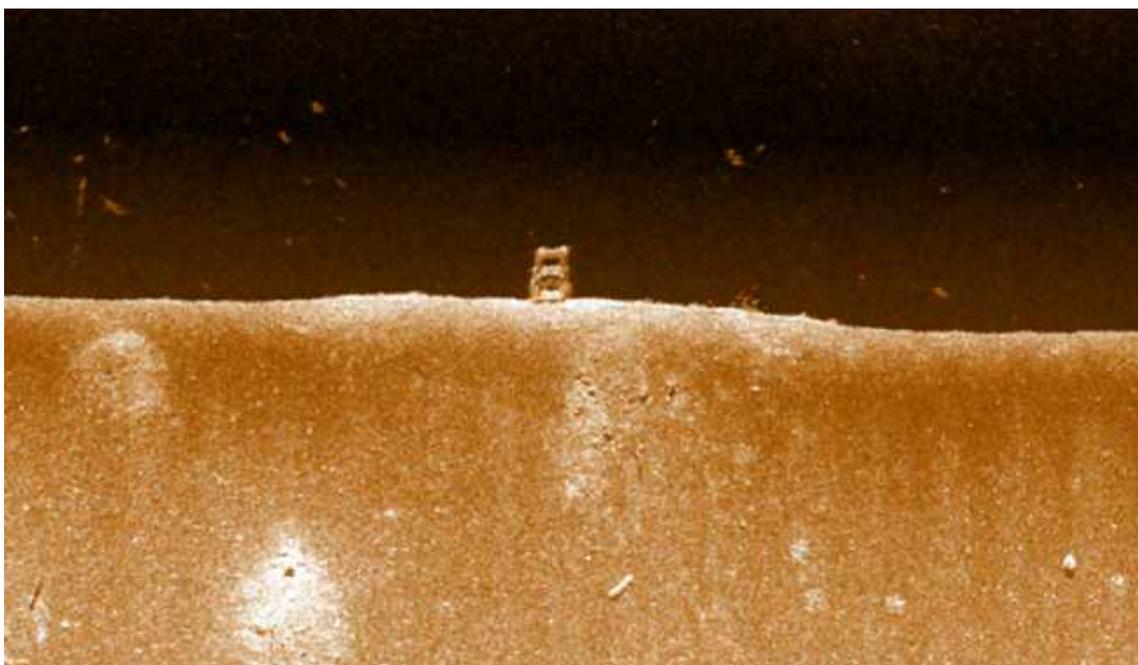


Figure 5.3: Side-scan sonar data image showing the rear end of the Citroën Traction Avant.

interested discovered by multi-beam or side-scan sonar survey in Austrian lakes¹. It is planned to record with the ROV underwater imagery of submerged structures to attempt 3D image based modelling. The success of this approach will be subject to the turbidity of the water.

5.2 Underwater magnetic prospection with the Austrian armed forces

Based on discussions with collaboration partner sergeant major Jürgen Zeitlhofer of the Austrian Armed Forces on the possibility of magnetometer surveys in shallow water, the Office for armour and defence technology constructed a wooden sensor carrier for five Fluxgate magnetometer probes mounted on the two hulls of a catamaran in front of a so called Pioneer boat. In April 2019 this system was tested in Lake Neusiedl, which despite its huge surface area of 315 km² only has a maximum water depth of less than two metres. The aim of these tests was to establish whether this system could be used for the prospection of submerged metal debris from aeroplane wrecks. It is thought that some 50 planes have crash landed in Lake Neusiedl in World War II. The LBI ArchPro supported this project by providing for the test a magnetometer system including the LoggerVis data acquisition software, which has the unique feature to be able to display the collected magnetic data in close to real time during the survey while providing a navigation solution. If needed, the system would be made available for use by the LBI ArchPro.



Figure 5.4: Underwater magnetic prospection on Lake Neusiedl with the Austrian Armed Forces.

5.3 Magnetometry survey at Moos/Attersee

In the close vicinity of the World Heritage Site 'Prehistoric Pile Dwellings around the Alps' an additional potential settlement area was surveyed in December 2019. A special feature of this region is a silted up area which lies directly on the west bank of Lake Attersee in the municipality of Seewalchen, village of Moos.

The topography of the area suggests that an elevated water level of Lake Attersee – in prehistoric times – indicates this area as a possible settlement site of the pile-dwelling culture. Since large parts of the fields consist of wet meadows, a first geomagnetic survey was conducted in December 2019.

¹ With its 191 m maximum depth, Lake Traunsee is Austria's deepest lake.

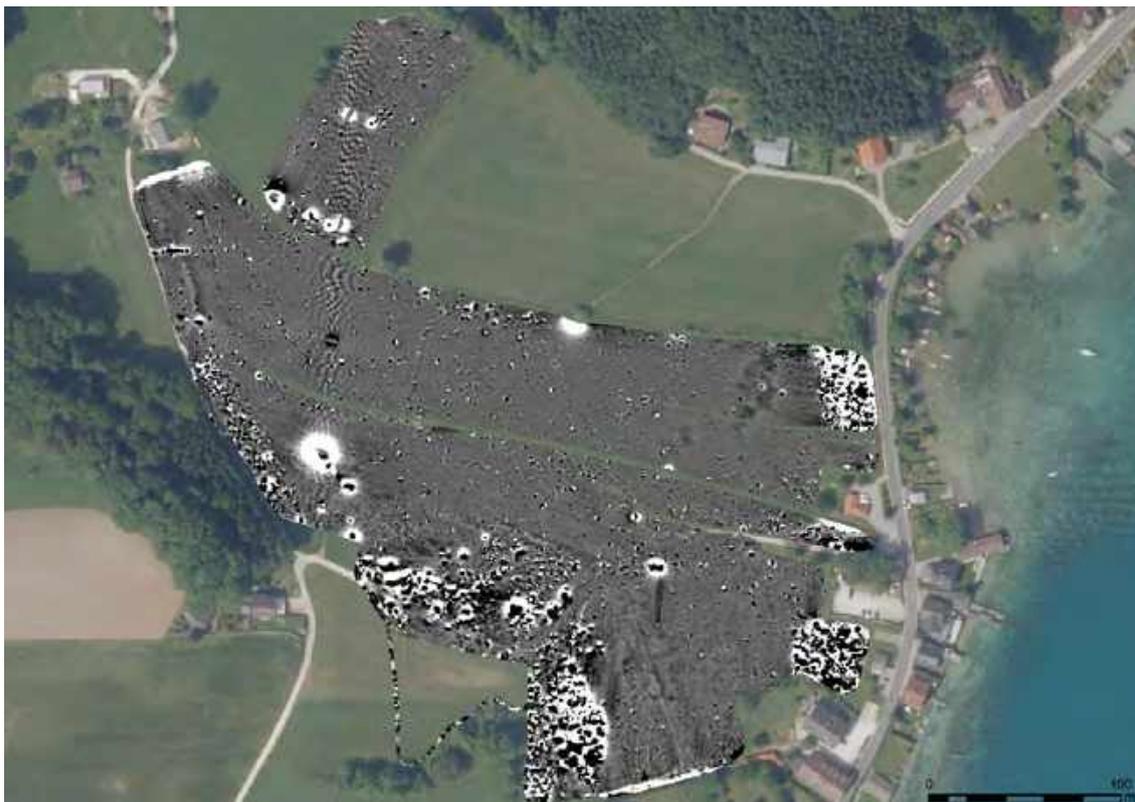


Figure 5.5: Magnetic prospecting at Moos on the shore of Lake Attersee.

A long dry period in autumn and the low temperatures of the winter months allowed a motorized survey even on the otherwise soaked meadows. However, the measurements did not reveal any obvious settlement site. Only a small area directly next to the former inflow to the lake might be interpreted as a potential settlement area.

6. Data management (DM)

Due to the large-scale case studies conducted by the LBI ArchPro we are confronted with resulting enormous datasets that require adequate management. Appropriate data management includes a comprehensive data description based on adequate meta-data definitions, hard- and software solutions to share the data with the partner organisations, long-term archiving and safe backup as well as data preservation solutions.

ArchPro data are distributed over four major locations: Langenzersdorf (LE), ZAMG, the Vienna Institute for Archaeological Science (VIAS) located at the Institute for Prehistory and Historical Archaeology (IPHA) of Vienna University, and the centralised server room of Vienna University's IT department (ZID). Without a dedicated and trained system administrator, several staff scientists do their best to manage the computing resources. The main file server (with two names, `filesftp.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+. In the near future, it may also act as portal server for public results served with ArcGIS online services. In addition, several GIT source-code hosting services and collaboration tools were evaluated in 2019. The open source tool Gitea will be installed in 2020 to manage internally developed software and facilitate collaboration between developers based in Vienna and Graz. Gitea also includes a bug and issue tracking system and a wiki. This will serve as a central hub for the documentation and discussion of software projects. It also helps to keep team members up to date and to understand the history and design decisions of the software.

LBI ArchPro's main site in Langenzersdorf (LE) is connected only via 4G mobile data service by 3/Hutchinson. The location uses a telecommunication access point close to the highway, which leads to variable and frequently low bandwidth. Given this slow internet connection on the one

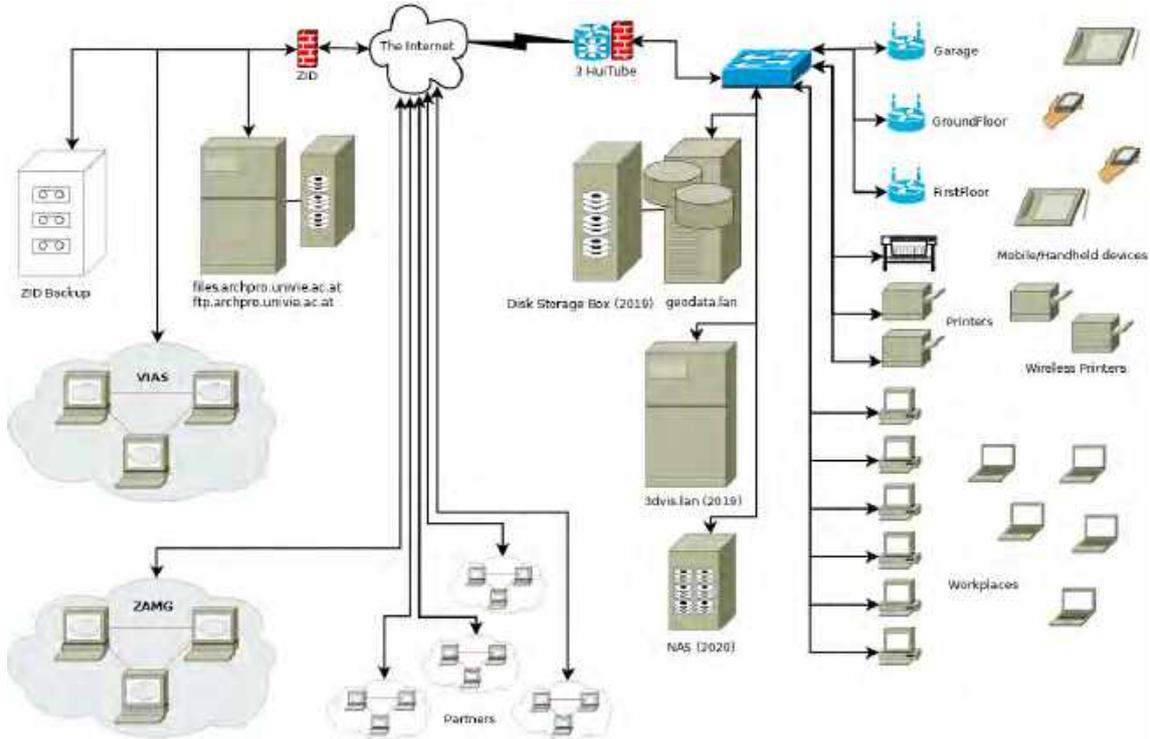


Figure 6.1: Data management concept.

hand and the large amounts of data on the other, a second server (named `geodata.lan` while LE infrastructure has no domain name or even connectivity from outside) has been installed in LE in 2018. This should act as centralised local network file storage for everyday work done in LE, and shall also run `geodata` services (ArcGIS server...). After initial experiments with ArcGIS for server in late 2018 and before these services could become active for production early in 2019, we needed more storage. Over several months in 2019 operating the files server in LE was however severely hampered by problems with an old disk storage box, several faulty harddisks and a wrong cable connection, which were finally solved. After another glitch with a failed routine update the CentOS7 operating system was scrubbed and replaced by Debian 10, given the latter's stability, and ArcGIS services depending on a RedHat-like distribution like CentOS will be configured in Virtual Machines. Raw storage filespace was increased from 16 to 48TB. The server should finally go into productive use early in 2020, and ArcGIS services should follow again later in 2020. In addition, the slow internet connection in LE shall be upgraded to fiber connection, to be newly introduced in the area in 2020. This step should make archival data transfer and backup from LE to the University-hosted files server much easier and faster.

Most of the data on this server are images created from the measurement data, can in principle be re-generated using ApSoft and therefore don't critically depend on another backup. However, the resulting data, geodatabases, derived images, ArcGIS projects etc., have to be regularly backed up. The intended solution is a nightly online rsync backup to the University files server, however the rather slow connection did so far not invite the actual implementation of this solution. A second server was brought to LE from the LBI for Clinical-Forensic Imaging. This currently acts as local backup, but shall become a local computing resource for volumetric 3D visualisations. Another 32TB NAS (network-attached storage, a simple dedicated files server) will be transferred from LBI CFI in 2020 and will take over local backup tasks. 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. Especially, all networked PCs were updated to Windows 10 by end of 2019. For technical reasons, some field PCs still have to run legacy versions of Windows, but are no longer connected to the Internet.

7. Data fusion (DF)

Over the last three years, several new fusion methods have been added to TAIFU (shorthand for the LBI ArchPro's Toolbox for Archaeological Image Fusion):

- multi-scale transform and sparse representation image fusion;
- geometric mean fusion;
- structure-aware fusion;
- multi-scale guided fusion;
- convolutional sparsity-based morphological component analysis fusion (Fig. 7.1);
- six Fejér-Korovkin wavelet filters for the wavelet-based fusion;

Many bug fixes and smaller improvements have been implemented as well:

- alpha values for the wavelet-based fusion;
- improved descriptions of the methods;
- *.flt import was completely reprogrammed to make it more robust;
- a sigmoid-based mapping for *.flt files;
- six new image quality measures:
 - standard deviation;
 - entropy;
 - revised mutual information;
 - mutual information & Tsallis entropy (Cvejic et al. 2006);
 - mutual information & Tsallis entropy (Nava et al. 2007);
 - sum of correlation of differences.

A TAIFU sprint in November 2019 aimed at evaluating all fusion algorithms implemented so far. This was achieved by creating a test data set, consisting of ground-penetrating radar and magnetometer imagery of five different case studies (Carnuntum, Deutschkreutz, Stonehenge, Velm, and Walchen). Using the test data sets, a more or less relevant range for every fusion method-specific parameter could be established. These ranges were fed into a function that computed all possible parameter permutations. Running all these permutations on a set of test images could be

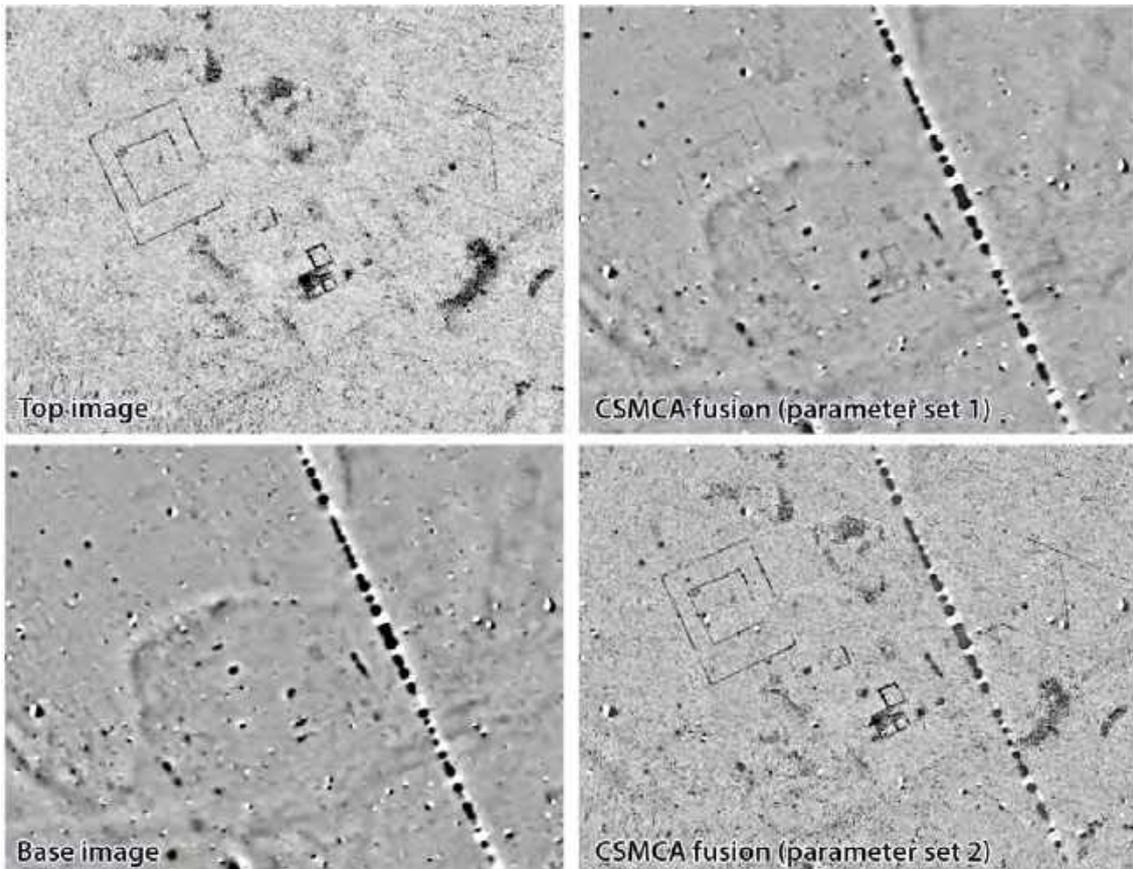


Figure 7.1: The top and base image of the Walchen test dataset (on the left) and two fused outputs using the Convolutional Sparsity-based Morphological Component Analysis (CSMCA) image fusion method on the right.

achieved by a newly developed Graphical User Interface or GUI (see Fig. 7.2).

With this GUI (which can be called from the main TAIFU interface), everyone can call TAIFU and tell which fusion methods should be run on which images. If more than one base and one top image are present, the user can also specify how these images should be combined: every base image with every top image, or only base image 1 with top image 1, base image 2 with top image 2 etc. The code also enables swapping of top-base images for those methods that are not-commutative as well as image inverting. The latter creates four possible permutations: base normal/top normal, base inverted/top normal, base normal/top inverted, base inverted/top inverted. Different image-specific alpha values can also be chosen. Right now, all but the pansharpening family of methods and the less useful dense-SIFT multi-focus method (which might be removed from TAIFU) can be batched. Moreover, Figure 10 illustrates that the batching GUI informs the user on the number of images that will be generated (in total as well as per method).

Evaluating the enormous amounts of newly generated fused outputs will still take several months. Afterwards, the best algorithms and its parameter values should be incorporated into ArchaeoAnalyst. To smoothly enable the latter, Andreas Lenzhofer has checked all possible options (with related requirements and costs) of integrating TAIFU algorithms into ArchaeoAnalyst.

So far, TAIFU was used in the Borre research. Those results were presented at CAA 2018 in Tübingen by Petra Schneidhofer.

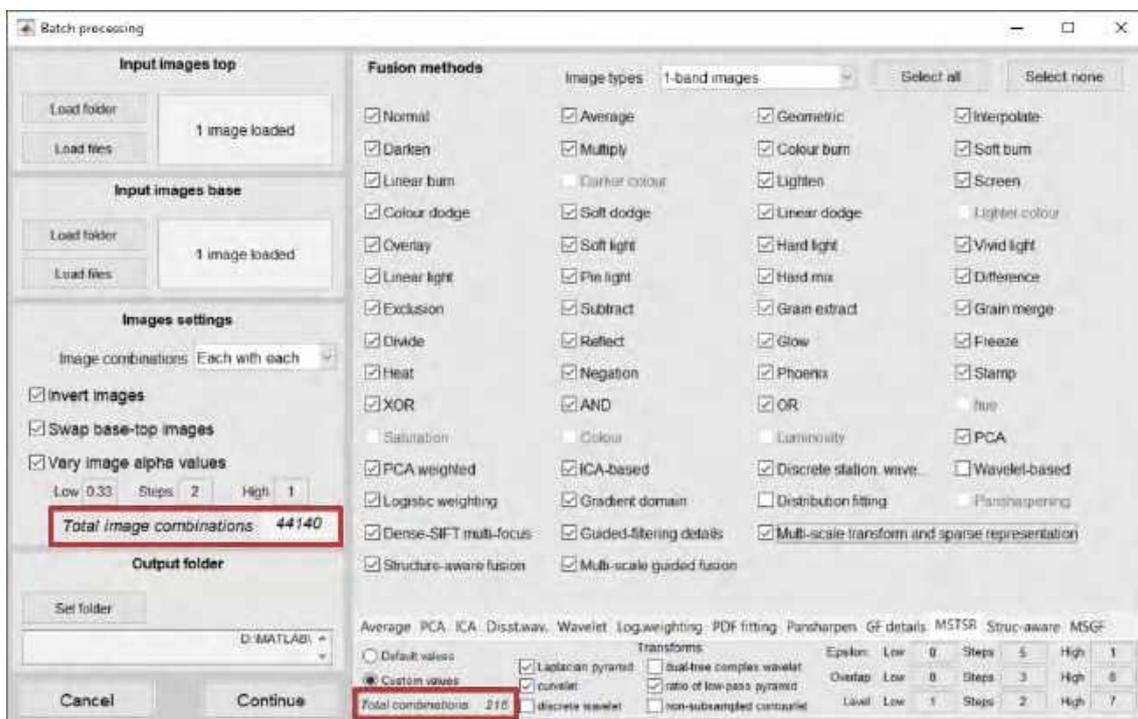


Figure 7.2: The current GUI that serves as an interface to TAFU's batching capabilities.

8. Semiautomatic feature extraction (FEX)

While it has been shown that direct 3D visualisation of GPR datasets is possible, the results are often suboptimal for archaeological tasks, notably interpretation. Therefore, image filters which suppress small structures, such as individual stones in the data, while emphasizing foundation walls, ditches or postholes (see Fig. 8.1), have been implemented. After filtering with, e.g. edge-preserving smoothing filters, the contours of such structures are clearly visible, which aids both interpretation and 3D visualisation. Future work will include in-depth research into the applicability of 3D filters for medical image analysis for GPR data and the adaptation of specific algorithms for image segmentation. Therefore, image filters have been investigated to optimally prepare the data for 3D visualisation with the goal to maximise the visibility of archaeologically relevant information by reducing the impact of noise. Edge-preserving smoothing filters based on the total variation locally remove noise in the data by blurring the images, while edges of the essential structures larger than a user defined threshold value are maintained. Applied to GPR datasets, such filters remove small structures like individual stones and noise, while emphasizing larger structures like walls, ditches

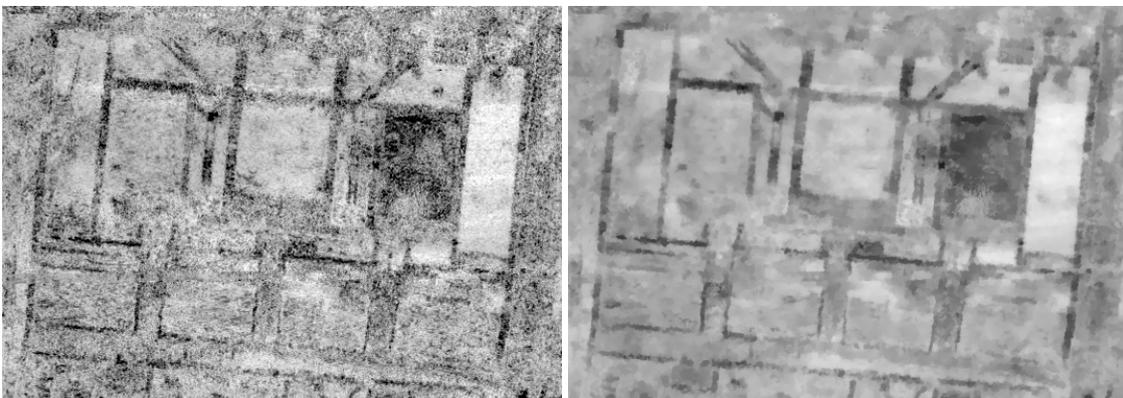


Figure 8.1: Original version of GPR dataset slice (left) and filtered version (right) emphasizing structures of foundation wall size while small structures like stones and bricks are suppressed.

or postholes (see Fig. 8.1). After filtering the contours of such structures are clearly visible, which aids both interpretation and 3D visualisation. The results can be further improved through fused visualisation of datasets obtained from different filters and parameter levels. Future work will include in-depth research into the applicability of other 3D filters from medical image analysis to GPR data. In addition, the applicability, of 3D image segmentation algorithms to GPR data will be further investigated to explicitly extract structures of interest from the dataset, which allows their more distinctive visualisation (see 8.2) and supports further investigations of the resulting 3D surfaces.

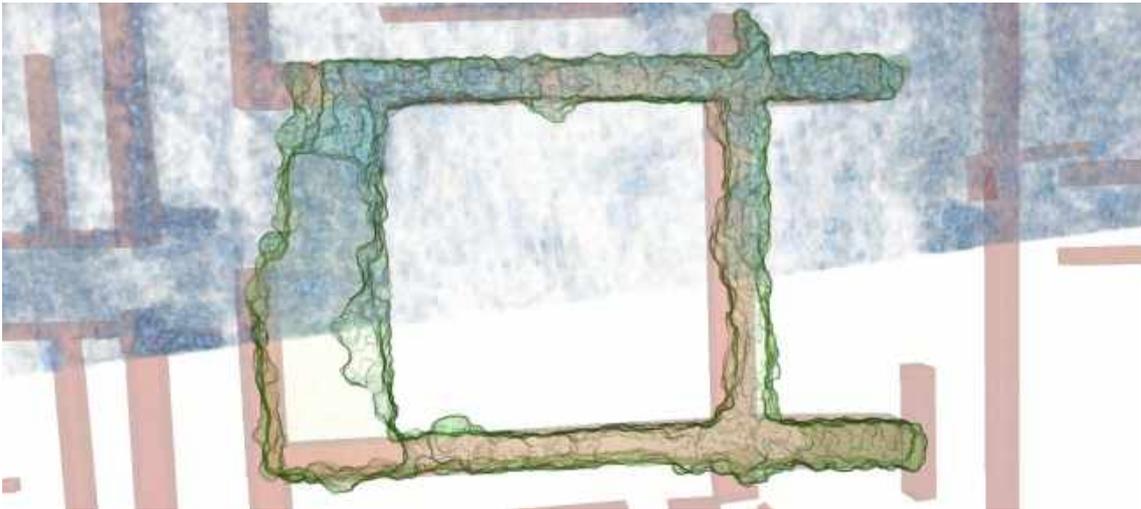


Figure 8.2: Combined visualisation of GPR datasets (blue), archaeological interpretation of Roman foundation (red) and semiautomatic segmentation of foundation walls of one building based on a filtered version of the dataset.

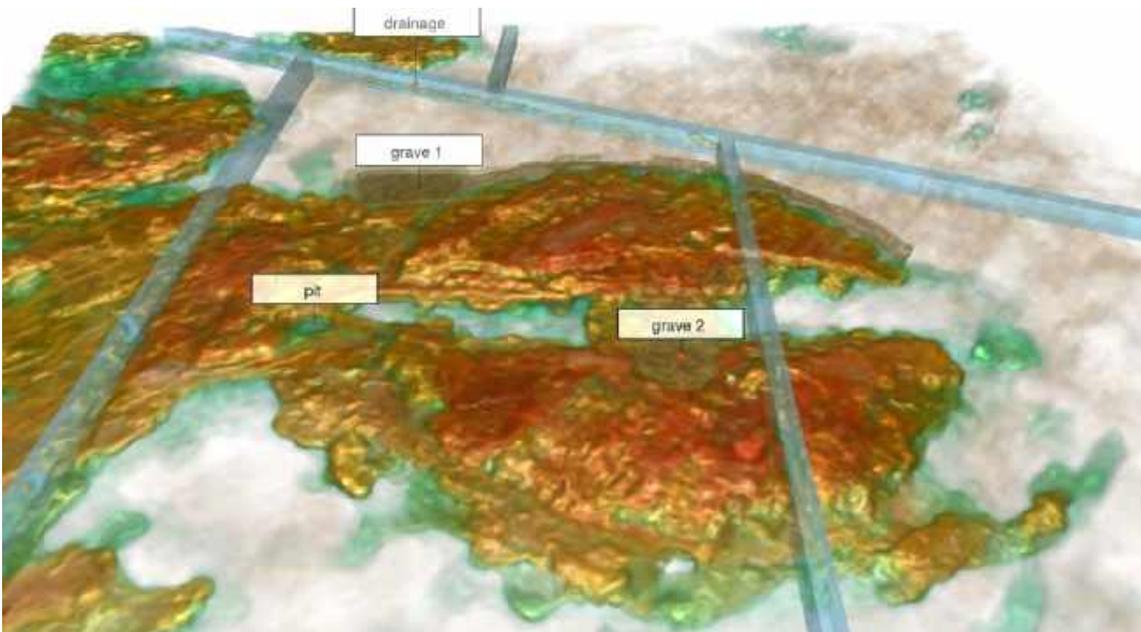


Figure 8.3: Illustrations of Viking burial site based on archaeological interpretation of 3D GPR data composed of 3D models of the grave and modern infrastructure annotated GPR volume visualisation revealing the shape of a Viking ship.

9. Reconstruction (REC)

Guidelines for scientifically sound reconstructions have been given in the London Charter and Seville Principles of Virtual Archaeology. A good reconstruction should indicate which parts of the reconstruction are indisputable (usually only what is still available in situ), and which are based on assumptions from parallel finds or other data. It should include, technical possibilities provided, within the model, easily accessible arguments for particular details, e.g. a roof with brick tiles could include an info tag “based on the highly magnetic signature indicating debris from lots of burnt clay roof tiles”. A workflow has to be developed with 7 reasons that includes the addition of such annotation tags. Before release to the public, the responsible archaeologist must work together with the modeller on annotating such critical parts. An alternative is an adjoining document that describes the workflow and reasoning. It may also be useful to involve other experts for the respective culture (the possible hyper-critical reviewers?) and discuss the model before publication of such a model.

The modelling workflow should also make absolutely sure to preserve object (survey) coordinates. If for technical reasons (double vs. single-precision floating point data) vertex coordinates cannot keep complete UTM (or GK, OSG, ...) data, a recorded “well-known offset” in a project coordinate system is a widely used workaround. It is very easy to define local coordinates by subtracting e.g. full thousands in the UTM raster coordinates. It **MUST BE ABSOLUTELY FORBIDDEN** to shift model or DEM parts around only visually with handles provided by the modelling program, and thereby losing coordinates, and just assembling model parts visually in the 3D editor. This has already resulted in positionally inaccurate models, which is embarrassing by today’s standards, given our expertise and insistence, elsewhere, on positionally accurate GIS data. Likewise, if the raster coordinates of the DEM are based on UTM or any other Cartesian survey grid, this means the North direction of “raster north” is almost certainly not exactly the direction to “true north”. In some critical cases like sunrise/sunset simulation in Stonehenge, this really matters. It is highly recommended to keep the model based on a Cartesian UTM (or other) raster and provide model coordinate offset and UTM Zone information in an accompanying text file (“README.txt” or similar) which ensures this information is also available for models converted/exported to other file formats.

While it has been shown that direct 3D visualisation of GPR datasets is possible, the results are often suboptimal for archaeological tasks, notably interpretation. Practical GPR data exhibit a high degree of local contrast changes due to the different reflection characteristics of, e.g. stones or clay. 3D visualisations based iso-surfaces delineate the surface of small objects like stones in the soil and human-made structures, However, by extracting surfaces, the volumetric nature of the data is sacrificed. Direct volume rendering, extensively used in medical imaging to visualise CT or MRI datasets, applied to GPR data leads to diffuse clouds where structures of archaeological interest can hardly be seen. This is exacerbated by the adverse effects of noise in the GPR acquisition and reconstruction process.



Figure 9.1: Virtual 3D model of a Linear Pottery Culture Longhouse.



Figure 9.2: 3D reconstruction of the Forum of Carnuntum integrated with GPR data visualisation underneath.

10. Simulation (SIM)

The term simulation is generally used for the scientific modelling of natural or human systems in order to gain insight into their functioning. Simulation can be used to illustrate and investigate the eventual real effects of alternative conditions and courses of action in dynamic systems. Archaeological sites or landscapes represent the remains of past dynamic systems. The developed reconstruction models represent certain states of the past dynamic systems, whereas the simulation represents changes within the systems over time.

Georg Zotti is co-developer of the popular Stellarium open-source desktop planetarium¹. This sky simulation engine had been enhanced earlier by a 3D foreground walkthrough simulation dedicated for research in archaeoastronomy (simulating the sky over past landscapes in combination with human-made structures like monument walls). The latest refinement in this environment, presented at SEAC2017, is the possibility to define model parts which are visible in a certain time only, using the built-in time interface of Stellarium to drive the presentation of building phases. This prevents misrepresentation of a monument under a wrong sky (Zotti, Schaukowitzsch and Wimmer 2018). Stellarium's quarterly releases are downloaded by approx. 400,000-700,000 users, mostly by amateur astronomers, but also by researchers of cultural astronomy.

For more lively scenes which also allow interaction with e.g. historical observation instruments, a game engine like Unity provides more options. An experimental interprocess interface between a Unity simulation environment and Stellarium has been presented at SEAC2018. In this simulation, the user operates historical astronomical observing instruments mostly from the second phase of the historical observatory of Maragha (Iran; ca. 1283-1317), but also the giant meridian instrument of Ulugh-Beg's Samarqand observatory (ca. 1425) under a sky background which gets delivered by Stellarium, either in form of static precomputed skyboxes, or even in a live mode. View direction and other display commands can be sent from Unity to Stellarium using its RemoteControl HTTP API. (Zotti 2018; Zotti, forthcoming; Zotti and Mozaffari, forthcoming). In this environment, also seasonal changes in the Unity landscape were tested, so that the ground vegetation cover changes from fresh grass in spring, dry grass in late summer, green grass in autumn, and frosted-over white

¹ <https://stellarium.org>



Figure 10.1: The Virtual Park of Astronomical Instruments combines the astronomically excellent sky simulation of Stellarium and allows for the virtual operation of historical pre-telescopic astronomical instruments in a game-realistic environment. Natural effects like reflection of the sky (including products of human imagination like the constellations, and those of human attempts to rationalize the sky, like celestial grids) on wind-rippled water surfaces or seasonally changing vegetation, and sound effects, can improve the immersive quality of the simulation.

in winter. Together with the natural difference in solar altitude and the seasonal changes in the night sky, this again raises realism in the simulation. Unfortunately, the programmatical modification of the vegetation layer is less well documented, so that trees so far don't show seasonal change. A game engine also allows simulation of wind-shaken vegetation or bird or other animal voices in the forest, which again may be driven by the season. The simulation of building phases can easily be solved in Unity, again using a time control module which is linked to Stellarium's time control to always provide the correct view of the sky or direction of sunlight. For applications where the sky and accurate celestial simulation are not important, these time control details can of course be implemented in Unity.

- Georg Zotti. The state of virtual archaeoastronomy with Stellarium. Commission C3 science meetings, International Astronomical Union XXX General Assembly, Vienna, August 2018.
- Georg Zotti. A Virtual Park of Astronomical Instruments. In Sonja Draxler and Max E. Lippitsch, editors, *Harmony and Symmetry (Proc.SEAC2018)* (forthcoming)
- Georg Zotti, Bernard Frischer and John Fillwalk: *Serious Gaming for Virtual Archaeoastronomy* (forthcoming)
- Georg Zotti and S. Mohammad Mozaffari: *A New Light on the Central Instrument of the Samarqand Observatory* (forthcoming)

11. Spatio-temporal reasoning (STR)

Any buried archaeological stratification incorporates **the spatial and temporal aspects of the archaeological site or landscape** in a more or less distinct manner. The single units and their topological relations reflect distinct events or time intervals relevant to the formation of the complete 4D dynamic system. The archaeological prospection process aims for the localization and detailed non-invasive exploration of the physical contrast within the buried archaeological stratification. The interpretative mapping approach of the LBI ArchPro has to be adapted to take into account/consider the basic stratigraphic structure of an archaeological site or landscape. Respective three-dimensional visualization techniques and interpretative mapping routines need to be developed to change the prospection approach from a 2.5 D mapping based on arbitrary depth levels or volumes towards a full 3D approach investigating the depicted elements of the archaeological stratification based on their respective physical parameters.

The stratigraphic excavation process in contrast to the non-invasive approach aims for the unearthing of the single units of stratification in the reverse order of their formation, along with all their descriptive attributes and topological relations, and to create a stratigraphic sequence, the fundamental diagrammatic representation of relative time for an archaeological site. It displays all uniquely identified units of stratification in a sequential diagram representing their relative temporal succession. It provides an inherent relative calendar, which is the testing pattern for the integration of any additional relative or absolute temporal information derived from the interdisciplinary post-excavation analysis of finds and samples. The destructive excavation process is an irreversible experiment that demands the definition of a comprehensive and universally applicable workflow, coherent rules and documentation parameters. Once stratification is removed by the excavation process, its further scientific analysis is based solely upon the record ideally formed by a complete 3D topographic record, a valid stratigraphic sequence, complete descriptive information, databases reflecting various attributes of deposits, surfaces, artefacts, eco-facts and samples extracted from the deposits. This is *the virtual representation of the primary stratified volume* – a concept to be further defined theoretically as *fully digital and four-dimensional, backed by a logical model*.

Any archaeological site or landscape is understood by the LBI ArchPro general theoretical approach as a physical volumetric body with limited spatial extent formed over a long period of

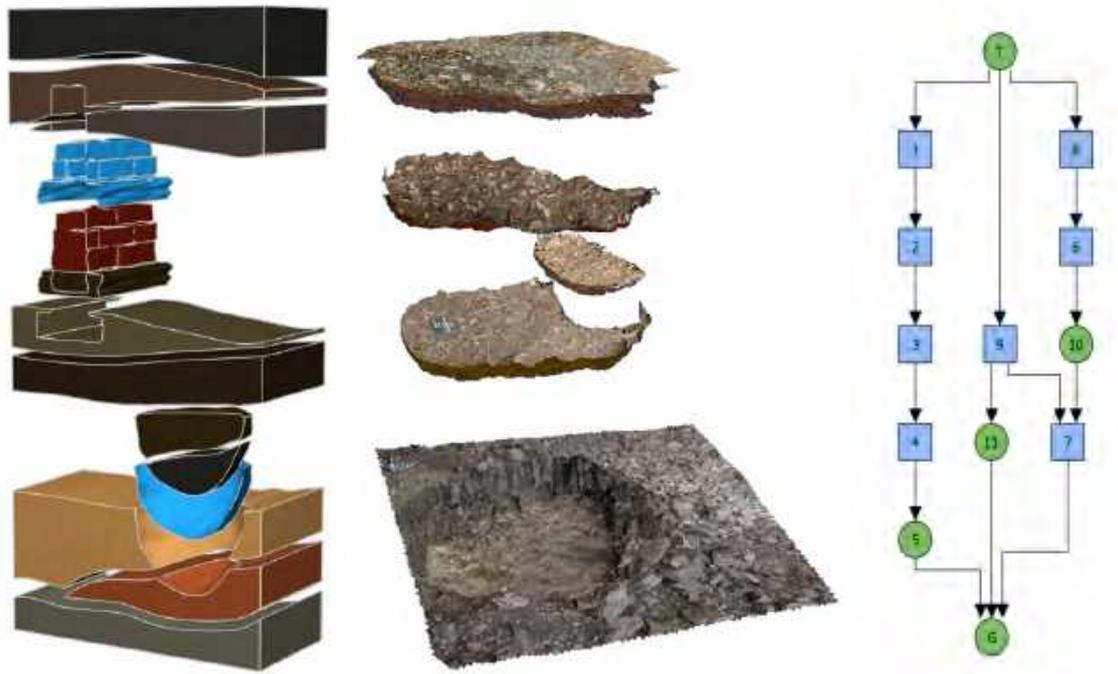


Figure 11.1: Left: A block model of principal elements of an archaeological stratification i.e. the stratigraphic units. Right: Compiled single surfaces from the bottom of a pit upwards through time with the respective HM

time. Usually, natural, anthropogenic and anthropogenic influenced physical or chemical processes contribute to the formation of a site, reflecting its environmental, historical and cultural settings. These volumes are organized by individual volumetric entities, the stratigraphic units, forming a unique stratification incorporating the spatial and temporal aspects of the site corresponding to distinct events and time intervals. Every stratigraphic unit can be characterized by its geographical or **spatial** position and extent, its observed topological relations in relation to the other units and its specific **temporal** characteristics. The Harris Matrix (HM), introduced in 1973 by the Bermudian archaeologists Edward C. Harris, is the de facto standard for the documentation of the topological relations of the archaeological stratification during the stratigraphic excavation process. The HM is not a matrix in mathematical terms but a sequential diagram representing the stratigraphic relations of all individual units of stratification. The initial definition and layout of an HM has been developed further by director of the LBI ArchPro in accordance with E.C. Harris in the 2000s and lead to a new convention implemented in software named Harris Matrix Composer (HMC).

Such a revised HM or stratigraphic sequence consists of two distinct type of nodes, rectangular symbols (\square) representing material deposits documented and removed by the excavation process and circular symbols (\circ) representing immaterial feature surfaces (pits, ditches etc.), whereby edges represent the topological relations also known as the stratigraphic relations between them. In mathematical terms, a stratigraphic sequence or HM is a directed acyclic graph with different nodes for the two types of stratigraphic units, i.e. deposits and surfaces where edges define the stratigraphic relation “is above”. A directed edge running from unit A to B means that A lies stratigraphically above B or in other words A is in superposition to B. This implies that A is later than B in respect to their relative temporal succession. If A and B are not in relation, their temporal position is open and not directly defined by the stratigraphic sequence.

Hence the stratigraphic sequence can be seen as a relative calendar but the exact dates of units

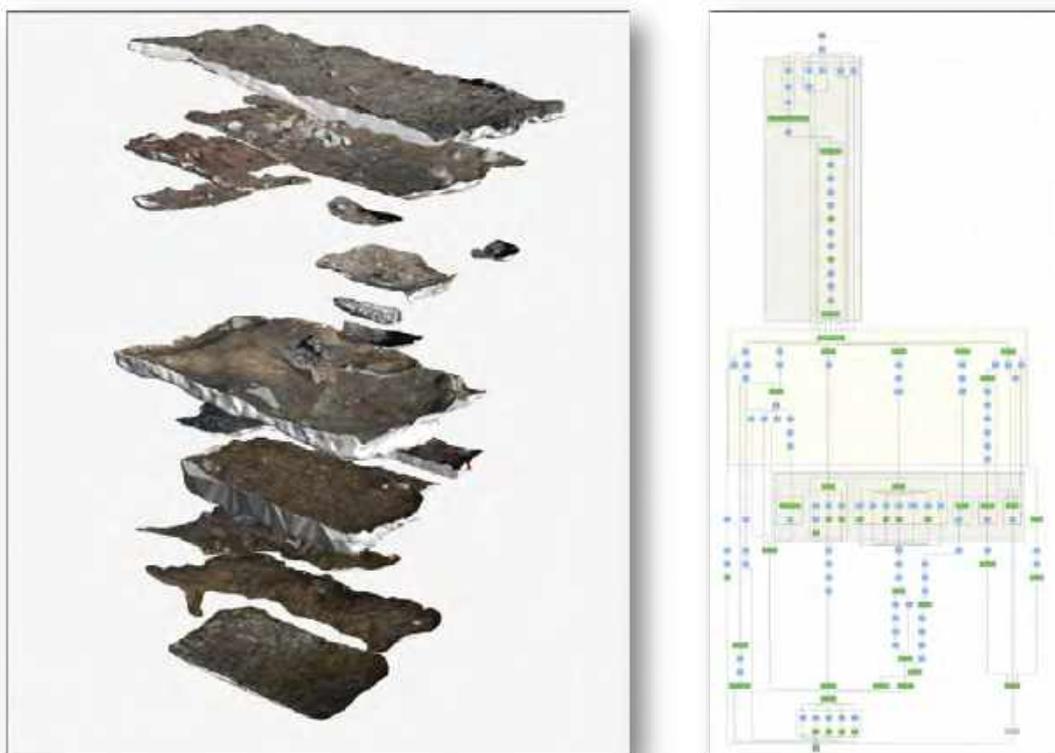


Figure 11.2: Explosion model of a part of the archaeological stratification at Falkenstein (AT) with the respective HM compiled in the HMC.

cannot be derived from it. Moreover, parallel strands do not necessarily mean that their units belong to the same time period, i.e. the horizontal alignment of units has no chronological meaning. This is a shortcoming as clear relations between stratigraphic or spatial and chronological or temporal properties would allow a more efficient and accurate analysis and a more robust interpretation. To be able to fully reconstruct the excavated volume and to derive the respective topological relations exemplifying the relative temporal succession, we have initiated the documentation of the surfaces of all excavated deposits in 3D, a process we have named Single Surface Planning, an important theoretical and practical extension of archaeological stratigraphic theory. The reconstruction of a site through time, i.e., the creation of the surfaces of each respective period, is achieved by the selection of subsets of the recorded single surfaces and by compiling the single surfaces from the bottom of the site upwards through time.

The development of the HMC software, a new editor for the compilation and validation of a stratigraphic sequence, is based on the results of previous research projects and was now taken over by the LBI ArchPro. The HMC is currently widely used in the archaeological community and even found application in forensics. The HMC is based on the powerful graph library yFiles from yWorks.

The HMC can handle large directed acyclic graphs with a high degree of usability and efficiency. Beside the stratigraphic or topological relations based on superposition, the HMC also supports temporal relations to define relationships of units of stratification that are not in superposition but can be defined in the way that A “is contemporary with” B or A “is later than” B. Additionally, it is possible to group subgraphs into structural entities called phases in the form A “is in phase with” B, C, . . . , X and into periods, assigning horizontal blocks of units to a historical epoch.

11.1 Harris Matrix Composer (HMC)

In 2019 the LBI ArchPro continued to offer licenses for the Harris Matrix Composer and received 45 requests from 18 different countries. Overall, 480 licenses have been sold since the release of the HMC to almost 300 institutions all over the world such as Belgium, Mexico, USA, UK, Norway and Italy including several prestigious universities and major archaeological institutes (e.g. Stanford, Cambridge, Oxford).

11.2 Harris Matrix Composer Plus (HMC+)

To address the shortcoming of missing explicit chronological relations or in other words the integration of a comprehensive time model to display not only the spatial but also the temporal properties of a stratigraphic sequence we developed the HMC further. The temporal relations are determined by post-excavation find analysis and scientific dating methods typically resulting in time intervals with certain probabilities. Allen introduced a sound theoretical framework for temporal reasoning also known as Allen's interval algebra. It is very well suited for chronology in archaeology as it considers imprecisions, uncertainties and relative relations.

We integrated a hierarchical time model based on the Allen Algebra into the HMC that enables the display of implicit and explicit temporal properties within a stratigraphic sequence. We investigated how stratigraphic and interval-based temporal relations can be combined in a consistent visual representation, resulting in the new tool named Harris Matrix Composer Plus (HMC+). The HM is therefore linked with the time model to assign units to time intervals. It is important that these time intervals can be fuzzy and overlapping as almost any archaeological dating method has uncertainties.

We implemented four concepts to represent the hierarchical time model that can be used to create respective temporal elements/ objects derived from archaeological practice. Initially, there is an absolute time axis with a resolution set to one year. The initial set-up of the left panel provides three empty time frames with increasing levels of granularity: ages, periods and phases. Every individual unit can be directly assigned to a distinct time interval. Ages represent the top level of the hierarchy and depict coarse time frames that correspond to long historical epochs, such as the

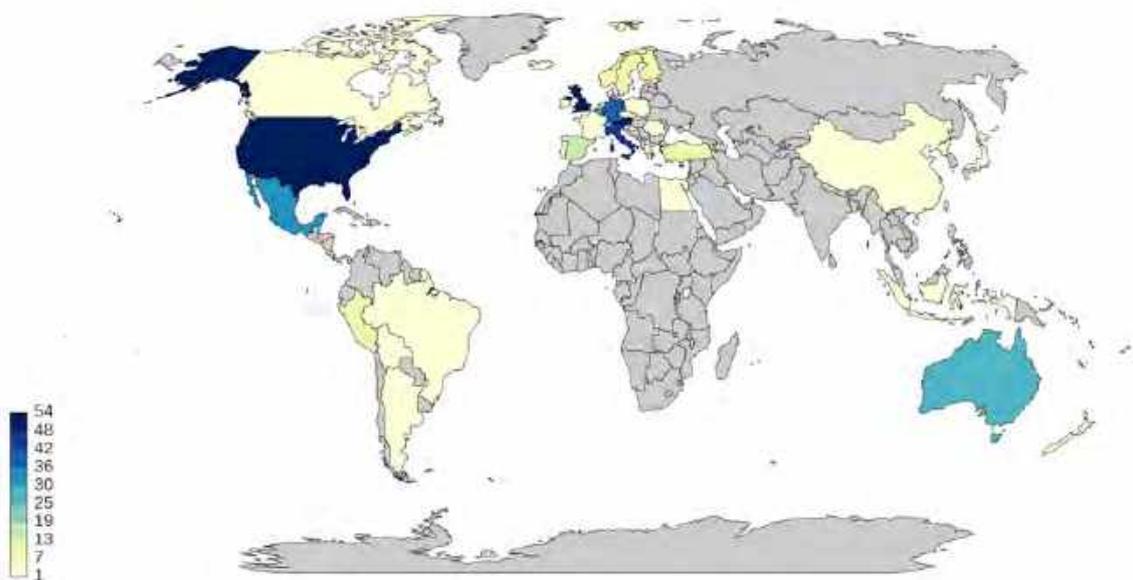


Figure 11.3: HMC license requests.

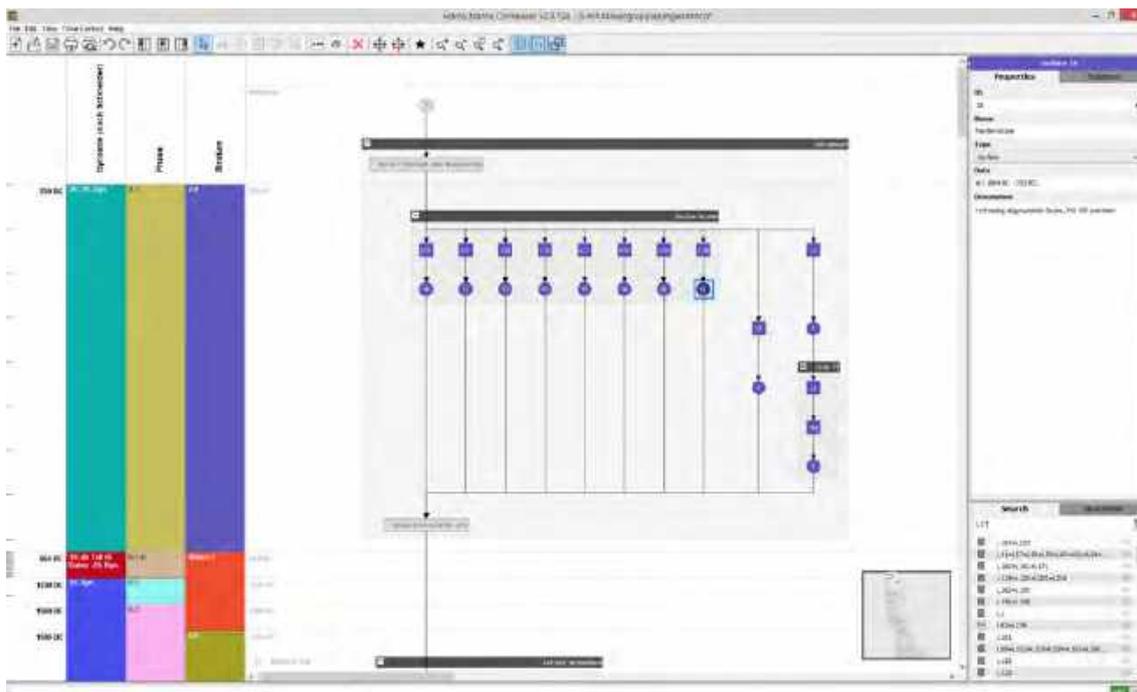


Figure 11.4: Main user interface components of the HMC+ design of the user interface of the HMC+. The left panel contains the hierarchical interval-based time model, the middle one contains the graph editor for creating and analysing an HM and the right one other interface components such as the property editor or the search dialogue.

Neolithic, the Bronze Age and Iron Age. Periods are subdivisions of ages, such as the Early, Middle and Late Neolithic (LN) or even broken down to smaller entities. Phases depict the bottom level of the hierarchy. They are site-specific time intervals resulting from the analysis of the stratification and the dating of finds and samples. All time frames and their respective subdivisions can be created and revised continuously by the archaeologist in the course of the post-excavation analysis. Per convention ages and periods do not allow for overlapping intervals. This means that every new element in the respective time frame, except the first one, must share a common border with an existing temporal element. In contrast, temporal elements in the phases time frame can overlap or have gaps between each other. This means that two consecutive elements must satisfy one of the following Allen relations: “x before y”, “x meets y”, “x overlaps y”. The HMC+ offers two different modes to date a unit: First, by assigning the individual unit to a defined interval of one of the three time frames or second by directly specifying an individual and distinct time interval, which is usually derived from archaeological or scientific dating methods such as ^{14}C .

In 2019, the main focus was on stability and performance improvements and bugs fixes, as well as extending the user manual and code documentation. Furthermore, all code has been migrated to Java 11, as Java 8 support will reach the end of life in December 2020. Existing features such as the Hierarchical Time Model editor, the Allen Interval Viewer, the Stratigraphic Unit Data Sheet Editor (SU sheet) and the GIS interface were further improved. The HMC+ ArcMap Add-In has also been developed for version 10.3 and the migration to ArcGIS Pro has been started. The Add-In was used in a proof of concept where a Harris Matrix with a hierarchical time model was linked to a GIS-based interpretation of a Carolingian Fresco in Münstair (see Figure 11.5). The development of HMC+ has reached the final phase and preparations for the open beta test phase in the first quarter of 2020 have started. The final public release is also planned in 2020.

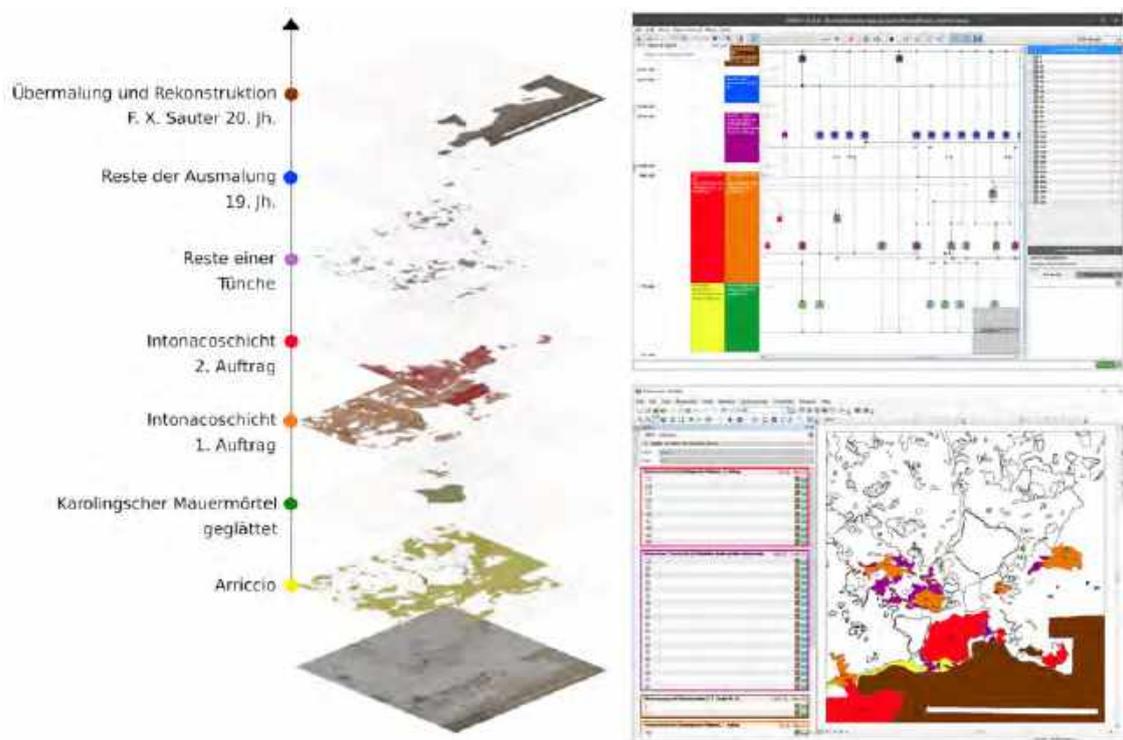


Figure 11.5: HMC+ ArcMap 10.3 Add-In showing a spatial-temporal analysis of the Müstair Fresco.

12. Dissemination and awareness (DISS)

12.1 Events

Seminary on Kreisgrabenanlagen on military training grounds

On February 27th 2019 a seminar on Kreisgrabenanlagen was organised in collaboration with the Amt für Rüstung und Wehrtechnik (ARWT) of the Austrian Federal Armed Forces at Benedekkasern in Bruck an der Leitha. After an introduction by the commanding officer of the military training ground, colonel Franz Neuhorst, brigadier Michael Janisch opened the seminar. Sergeant Major Jürgen Zeitlhofer presented the collaboration between the LBI ArchPro and the ARWT and synergies regarding ordnance detection capabilities. Wolfgang Neubauer spoke about prehistoric and historic monuments on military training ground. Michael Doneus talked about the archaeological landscape long Leitha river, and Mario Wallner presented the first prospection results from the Kreisgrabenanlage Traxlergraben.

Symposium DigiKult Krems, Lower Austria, 2.-3.4.2019

In April 2019 the LBI ArchPro organized the symposium „DigiKult – Digital Methods for Cultural Property Protection and Cultural Heritage Management - Potential and Limitations“ together with the Department for Building and Environment at the Donau-Universität Krems (DUK).

The main objective of the event was to offer a multidisciplinary forum to discuss relevant topics and specific issues in cultural heritage protection and management and the application of digital methods for this purpose. It provided a unique opportunity for the LBI ArchPro and its partners to gain insight into the DUK's substantial experience of creating practice-oriented solutions in regard to the management of cultural property and related issues such as the assessment and implementation of respective legal stipulations. Furthermore, the team of the LBI ArchPro and its collaboration partners shared experiences in the application of digital methods for the protection of cultural heritage, especially highlighting good practices from specific case studies such as the UNESCO World Heritage sites of Carnuntum, Stonehenge and Prehistoric Pile Dwellings in Upper Austria.



Figure 12.1: Workshop *Status quo, urgent demands and future perspectives of the LBI ArchPro*.

Workshop *Status quo, urgent demands and future perspectives of the LBI ArchPro* at Poysdorf, Lower Austria, 3.10.2019

In October the institute brought together the main team, the partners and the LBI partner board and scientific advisory board members for a one-day workshop in Poysdorf (Lower Austria) to review the progress that was achieved in the last 10 years, to reflect on the status quo and to structure and prioritize the scientific programme of the coming years.

Working in groups the participants engaged in stimulating and productive discussions that addressed urgent demands, the requirements of the partners and the strategic direction for the upcoming years to actively shape the institute's common future.

Forschungsfest NÖ, 27.9.2019

In September, the LBI ArchPro participated at the Forschungsfest NÖ for the second time. The event was organised by the county of Lower Austria at the Palais Niederösterreich in Vienna and attracted more than 12.000 visitors. A selected team of the LBI ArchPro presented an insight into novel, non-invasive technologies in archaeology and their application on cultural heritage sites. Visitors could experience a virtual flight over the prehistoric landscape of Stonehenge, a walk through the taverns of Carnuntum or explore a Viking hall in Norway. Young researchers and interns of the institute were also involved in the event and got the opportunity to practice their skills of communicating scientific research to a broad audience.

LBG Meet Science, 14.5.2019

In May the LBG hosted its biennial LBG Meet Science event with the theme "Digitalisierung – Visualisierung – Vermittlung" at the Semperdepot. More than five hundred guests from research, politics and industry visited the exhibition that presented current research projects of the Ludwig Boltzmann Institutes.



Figure 12.2: LBG Meet Science.

The LBI ArchPro presented its new research collaboration with the Ludwig Boltzmann Institute for Clinical Forensic Imaging. Together, the institutes developed the idea of applying cutting-edge 3D visualization and medical image processing techniques to archaeological prospection data. These techniques allow a visual three-dimensional visualization of archaeologically relevant structures in archaeological prospection data sets to facilitate their archaeological interpretation. During the event, the audience experienced the potential of the technology for the virtual exploration of archaeological monuments such as the Roman city of Carnuntum in a VR environment.

Schwarzenbach

One new house reconstruction was built around an exhibition container (8.9×4.7 m) which was equipped with air condition, showcases, a detailed model of a Celtic house, a 3D printed section model through the rampart and construction of the fortification and information panels. A large TV monitor presents a narrated film. The main installation in this container is a CNC milled landscape model (1.7×0.96 m) of the Schwarzenbach hill, onto which varying content is projected to tell the story and development of the early settlements on the hill, from the Neolithic to the La Tene epoch. A second screen behind the model provides additional information (textual narration, images) synchronized to the projected maps. The projection geometry required to cut an opening through

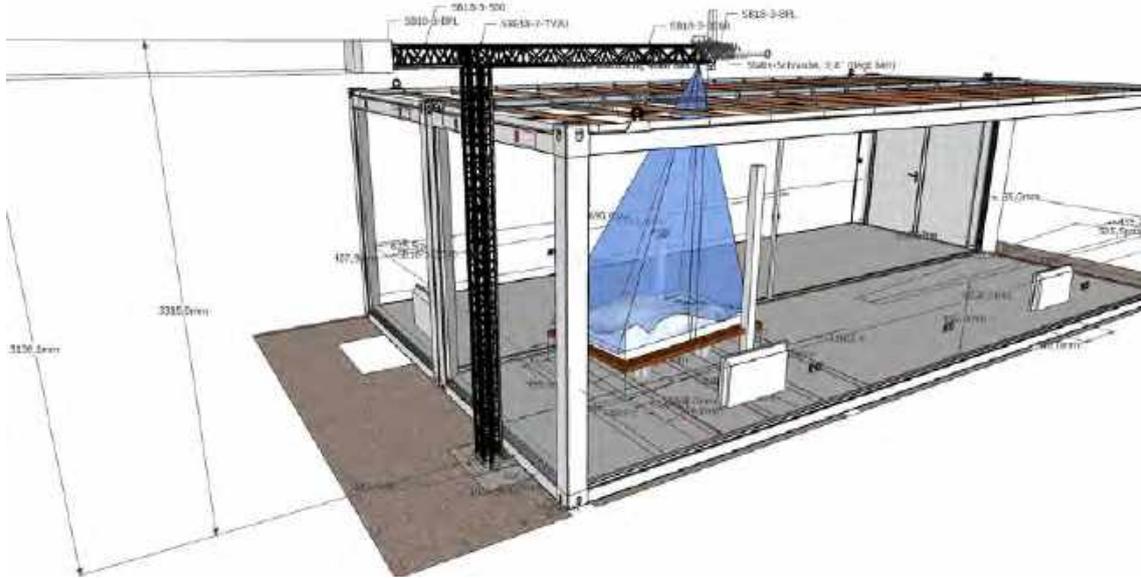


Figure 12.3: Concept of projection model for the Schwarzenbach exhibition container.



Figure 12.4: Opening of the Schwarzenbach exhibition.

the container's roof. To reduce the transmission of vibrations from the visitors moving on the container floor to the container or projector, the model has been placed on pillars that are resting on their own foundations, and the projector is attached to a truss beam secured to the enclosing house construction. After installation, a slight mismatch between projection and model can be adjusted by the present museum staff by shifting the model on its table and fine-tuning the projection.

The new exhibition at the open-air museum in Schwarzenbach (Lower Austria) was officially opened on May 30th. Two new Celtic houses had been setup at the open air museum with one of the buildings being equipped with a container that features virtual and media installation presenting latest research results from the site such as a projection mapped model. A virtual reconstruction of

the site and fortifications was done together with Sandro Lochau, a graduate student in “Scientific Visualization” at the Zurich University of the Arts. The event received considerable attention among the local and regional community: more than 300 guests attended the celebration which also featured a live Celtic barbecue. Concurrently, a press release was issued covering the most recent research activities and results on the Burgberg of Schwarzenbach.

The Schwarzenbach dissemination project is funded by ecoplus, the County of Lower Austria and the University of Vienna.

Open day at the KGA Velm excavation, 19.7.2019

During the excavation at the KGA Velm the team organized an open day at the archaeological site. The event generated overwhelming interest among the local population and counted over 500 visitors. The public TV channel ORF2 covered the excavation on the local news including a live interview with the team on site.



Figure 12.5: Open day at the excavation in Velm on Friday July 19th 2020. Photo: Walter Karlik.

12.2 Scientific publications and presentations

Books

- Czajlik, Zoltán, Matija Črešnar, Michael Doneus, Martin Fera, and Hellmuth Kramberger, Anja, Mele, Marko, eds. (2019). *Researching Archaeological Landscapes Across Borders. Strategies, Methods and Decisions for the 21st Century*. Graz-Budapest: Archaeolingua.
- Rind, Michael M. and Aurelia Dickers, eds. (2019). *Archäologie in Westfalen-Lippe 2018 (Band 10): Band 10*. Vol. 10. Archäologie in Westfalen-Lippe. Langenweißbach: Beier & Beran. ISBN: 9783957411136.

Articles

- Coolen, Joris and Hans-Otto Pollmann (2019). “Ein weiteres Erdwerd und seine Siedlung der Linearbandkeramik in Willebadessen-Eissen”. In: *Archäologie in Westfalen-Lippe* 18, pp. 48–52.
- Dresler, Petr, Peter Milo, Tomas Tencer, Michal Vágner, and Miroslav Dejmal (2019). “Non-destructive research into the field systems and the structure of the built-up area of the deserted medieval village of Vojšice (Hodonín district)”. In: *Archaeologia historica* 44.1, pp. 269–287.
- Gabler, Manuel, Immo Trinks, Erich Nau, Alois Hinterleitner, Knut Paasche, Lars Gustavsen, Monica Kristiansen, Christer Tønning, Petra Schneidhofer, Matthias Kucera, and Wolfgang Neubauer (2019). “Archaeological Prospection with Motorised Multichannel Ground-Penetrating Radar Arrays on Snow-Covered Areas in Norway”. In: *Remote Sensing* 11.21, 2485ff. ISSN: 2072-4292. DOI: 10.3390/rs11212485.
- Gibson, Alex, Wolfgang Neubauer, Sebastian Flöry, Petra Schneidhofer, Mike Allen, Enid Allison, Wendy Carruthers, Dana Challinor, Charles French, Garry Rushworth, and Alison Sheridan (2019). “Survey and Sampling at the Castle Dykes Iron Age “Henge”, Wensleydale, North Yorkshire”. In: *The Antiquaries Journal* 18, pp. 1–31. ISSN: 0003-5815. DOI: 10.1017/S0003581518000628.
- Gugl, Christian, Silvia Radbauer, and Mario Wallner (2019). “Archäologische Prospektion 2012–2017 in der Flur Gstettenbreite – ein Beitrag zur Entwicklung vorstädtischer Siedlungszonen in Carnuntum”. In: *Carnuntum Jahrbuch* 2019.
- Missinne, Stefaan and Geert Verhoeven (2019). “Leonardo Depicted America: Misread as the Moon”. In: *Advances in Historical Studies* 08.04, pp. 139–147. ISSN: 2327-0438. DOI: 10.4236/ahs.2019.84011.
- Sevara, Christopher, Martin Wieser, Michael Doneus, and Norbert Pfeifer (2019). “Relative Radiometric Calibration of Airborne LiDAR Data for Archaeological Applications”. In: *Remote Sensing* 11.8, p. 945. ISSN: 2072-4292. DOI: 10.3390/rs11080945.
- Štuhec, Seta, Geert Verhoeven, and I. Štuhec (2019). “Modelling building costs from 3D building models - estimating the construction effort from image-based surface models of dry-stone sheperd shelters (Kras, Slovenia)”. In: *ISPRS - International Archives of the Photogrammetry, Remote Sensing and Spatial Information Sciences XLII-2/W9*, pp. 691–698. ISSN: 2194-9034. DOI: 10.5194/isprs-archives-XLII-2-W9-691-2019.
- Verhoeven, Geert (2019c). “Resolving some spatial resolution issues – Part 2: When diffraction takes over”. In: *AARGnews* 59, pp. 12–23. ISSN: 1756-753X. URL: <https://doi.org/10.5281/zenodo.3518177>.

Zotti, Georg and Wolfgang Neubauer (2019). “Beyond the landscape: analysis of Neolithic circular ditch systems of Lower Austria with advanced virtual archaeoastronomy”. In: *Virtual Archaeology Review* 10.21, pp. 90–102.

Conference contributions

Gugl, Christian and Mario Wallner (2019). “Die Kaserne der Statthaltergarde in Carnuntum (Pannonia superior)”. In: *Authenticity and Experience: Proceedings of the international conference*. Ed. by Zoltán Havas. Aquincum nostrum II, pp. 21–54.

Hinterleitner, Alois, Ralf Totschnig, Klaus Löcker, Hannes Schiel, and Tobias Bendeguz (2019). “Modelling the layer between topsoil and subsoil using magnetic prospection data”. In: *New Global Perspectives on Archaeological Prospection*. Ed. by James Bonsall. Archaeopress, pp. 282–285. ISBN: 9781789693065.

Kainz, Jakob (2019). “Addressing archaeological research questions using geophysical surveys - a landscape study”. In: *New Global Perspectives on Archaeological Prospection*. Ed. by James Bonsall. Archaeopress, pp. 355–358. ISBN: 9781789693065.

Neubauer, Wolfgang, Alexander Bornik, Mario Wallner, and Geert Verhoeven (2019). “Novel volume visualisation of GPR data inspired by medical applications”. In: *New Global Perspectives on Archaeological Prospection*. Ed. by James Bonsall. Archaeopress, pp. 309–312. ISBN: 9781789693065.

Schneidhofer, Petra, Christer Tønning, James Eogan, Erich Nau, Alois Hinterleitner, Ian Russell, Terje Gansum, and Wolfgang Neubauer (2019). “When the Norsemen return: Complementary GPR surveys at the Viking Age site of Woodstown, County Waterford, Ireland”. In: *New Global Perspectives on Archaeological Prospection*. Ed. by James Bonsall. Archaeopress, pp. 91–95. ISBN: 9781789693065.

Sevara, Christopher, Michael Doneus, Erich Draganits, Roderick B. Salisbury, Cipriano Frazetta, and Doris Jetzinger (2019). “Innovating Archaeological Investigations in Mediterranean Landscapes: Contributions from the Prospecting Boundaries Project”. In: *New Global Perspectives on Archaeological Prospection*. Ed. by James Bonsall. Archaeopress, pp. 107–110. ISBN: 9781789693065.

Trinks, Immo, Wolfgang Neubauer, Timothy Taylor, Mario Wallner, Klaus Löcker, and Jutta Leskovar (2019). “High-resolution underwater archaeological prospection of Upper Austrian pile dwellings and lakes using multi-beam and sediment sonar”. In: *New Global Perspectives on Archaeological Prospection*. Ed. by James Bonsall. Archaeopress, pp. 21–23. ISBN: 9781789693065.

Wallner, Mario, Immo Trinks, Ingrid Schlögel, Alois Hinterleitner, Hannes Schiel, Tanja Trausmuth, Fabio Colivicchi, Maurizio Forte, and Wolfgang Neubauer (2019). “Investigating a tumulus in the Etruscan necropolis of Banditaccia - Applying multiple non-invasive prospection methods on a World Heritage Site”. In: *New Global Perspectives on Archaeological Prospection*. Ed. by James Bonsall. Archaeopress, pp. 115–118. ISBN: 9781789693065.

Talks

Bornik, Alexander (13.12.2019). *Integrierte Visualisierung von heterogenen 3D-Daten in Archäologie und Anthropologie*. Graz, Austria.

Doneus, Michael (2.4.2019). *The impact of aerial archaeology on archaeological research and landscape archaeology*. Paris, France.

- (9.4.2019). *Airborne Laser Scanning for Archaeology: Potential, Limitations and Latest Developments*. Paris, France.
 - (12.2.2019). *APIS – a Digital Inventory of Remote Sensing Data for Archaeological Heritage*. Wien, Austria.
 - (27.2.2019). *Die archäologische Landschaft entlang der Leitha. Neueste Ergebnisse archäologischer Fernerkundung*. Bruckneudorf, Austria.
 - (16.4.2019). *Prospection, excavation and interpretation. Theory and practice*. Paris, France.
 - (19.4.2019). *Understanding archaeological landscapes through non-invasive approaches*. Paris, France.
 - (19.9.2019). *Understanding archaeological landscapes through non-invasive approaches*. Leiden, Netherlands.
 - (14.11.2019). *Blick in die Vergangenheit – Archäologie aus der Luft*. Eggenburg, Austria.
 - (24.-26.10.2019). *Landschaftsarchäologie an der Schnittstelle zwischen Natur- und Kulturwissenschaft: Festvortrag*. Mistelbach, Austria.
- Doneus, Michael, Nives Doneus, and Christopher Sevara (11.5.2019). *Landscape changes and archaeological prospection*. Pula, Croatia.
- Doneus, Michael, Maria Shinoto, Irmela Herzog, Nakao Nakamura, Hideyuki Haijima, Onishi, and Tomokazu (28.8.-1.9.2019). *UAV-based Airborne Laser Scanning in densely vegetated areas: Detecting Sue pottery kilns in Nakadake Sanroku, Japan*. Sligo, Ireland.
- Doneus, Nives, Wolfgang Neubauer, Michael Doneus, and Mario Wallner (1.-5.4.2019). *Römerzeitliche Landparzellierung am Beispiel von Halbturn, Österreich*. Würzburg, Deutschland.
- Filzwieser, Roland (9.8.2019). *Eine Reise mit dem 3D Laser-Scanner von der Gegenwart in die Vergangenheit*. Raabs/Thaya. URL: <http://www.jungeuni-waldviertel.at>.
- (2.-3.April 2019). *Archaeological prospection of forgotten and massively threatened medieval rural structures – Case studies from Europe*. Krems.
- Gugl, Christian, B. Grammer, Mario Wallner, Nives Doneus, and Michael Doneus (5.11.2019). *Settlement and population structures in Northwest-Pannonia*. Iasi, Romania.
- Herzog, I., Michael Doneus, Maria Shinoto, Hideyuki Haijima, and Nakao Nakamura (5.11.2019). *Testing ALS Visualisation Software for Detecting Kiln Remains in a Densely Vegetated Area in Japan*. Vienna, Austria.
- Hinterleitner, Alois (21.10.2019). *Geophysikalische Prospektion in der Archäologie – neueste Entwicklungen hin zu hochauflösenden großflächigen Anwendungen*. Wien.
- Kucera, Matthias (2.-3.April 2019). *Laserscanning und image based modelling of the UNESCO World Heritage sites of Hallstatt, Tanum and Akrotiri*. Krems.
- Löcker, Klaus (2.-3.April 2019). *Large-scale non-invasive prospection of the UNESCO World Heritage site Ephesos*. Krems.
- Neubauer, Wolfgang (12.9.2019). *Kleinhadersdorf - die ältesten Bauern im Weinviertel*. Kleinhadersdorf, Austria.
- (21.10.2019). *Geowissenschaftliche Methoden in der archäologischen Prospektion*. Wien.
 - (22.10.2019). *Moderne Archäologie*. Marbach, Schweiz.

- (23.10.2019). *Archäologie ohne Spaten – Von den Wikingern bis nach Triesen*. Triesen, Fürstentum Liechtenstein.
- (27.02.2019). *Prähistorische und historische Monumente auf militärischen Truppenübungsplätzen*. Benedek Kaserne, Bruckneudorf, Austria.
- (25-26.10.2019). *New Archaeological Perspectives on Viking Slavery*. Bonn, Deutschland. URL: <https://www.dependency.uni-bonn.de/en/events/slaves-serfs-and-free-labour-in-medieval-northern-europe>.
- (2.-3.April 2019). *Durrington Walls - a superhenge in the UNESCO World Heritage site Stonehenge*. Krems.
- Neubauer, Wolfgang and Alexander Bornik (2.-3.April 2019). *Visualisation of 3D ground penetrating radar data sets - the Roman forum of Carnuntum*. Krems.
- Neubauer, Wolfgang and Roland Filzwieser (29.-31.10. 2019). *Non-invasive archaeological prospection of Pliska*. Shumen, BG.
- Neubauer, Wolfgang, Christoph Traxler, Andreas Lenzhofner, and Matthias Kucera (23-27 April 2019). *The Harris Matrix Composer+, a new tool to build stratigraphic sequences integrating an interval based time model*. Kraków, Poland.
- Schlegel, Jona (2.-3.April 2019). *Speicher-Herforst - a Roman industrial landscape in the hinterland of the Augusta Treverorum (Trier, UNESCO World Heritage)*. Krems.
- Sevara, Christopher, Michael Doneus, Erich Draganits, Roderick B. Salisbury, Cipriano Frazetta, and Doris Jetzinger (28.8.-1.9.2019). *Innovating Archaeological Investigations in Mediterranean Landscapes: Contributions from the Prospecting Boundaries Project*. Sligo, Ireland.
- Studnicka, Nikolaus and Mario Wallner (2.-3.April 2019). *The combination of ground penetrating radar, terrestrial and unmanned laser scanning - the Renaissance castle Rosenberg*. Krems.
- Trausmuth, Tanja and Alexandra Vonkilch (2.-3.April 2019). *Visiting the Etruscan cities of Cerveteri and Tarquinia (UNESCO World Heritage) and Vulci, Italy*. Krems.
- Trinks, Immo (21.11.2019). *Extensive high-resolution GPR measurements for archaeological prospection*. Invited keynote lecture at EuroGPR 2019 in Wrocław, Poland.
- (12.03.2019). *Transforming near-surface geophysical archaeological prospection*. International Open Workshop Socio-Environmental Dynamics over the Last 15,000 Years: The Creation of Landscapes VI, Kiel University.
- (29.05.2019). *Großflächige hochauflösende geophysikalische archäologische Prospektion*. Invited talk at the "Seminar Aktuelle Forschungsthemen" (SAFT) of the Institute for Geosciences, Kiel University.
- (2.-3.April 2019). *Prospecting the UNESCO World Heritage sites 'Prehistoric Pile Dwellings' in Upper Austria*. Krems.
- Trinks, Immo, Wolfgang Neubauer, Timothy Taylor, Mario Wallner, Klaus Löcker, and Jutta Leskovar (20.-22.2.2019). *Hochauflösende unterwasserarchäologische Prospektion oberösterreichischer Pfahlbauten und Seen mit Fächerecholot und Sediment-Sonar*. Dreiländertagung OVG - DGPF - SGPF 2019. Wien.
- Verhoeven, Geert (2.-3.April 2019). *Photogrammetric documentation of frescoes of the Minoan Bronze Age settlement of Akrotiri, Santorini*. Krems.
- Verhoeven, Geert Julien (2.09.2019). *The 3D datafication of cultural heritage: more than just a flash in the pan? Openins session keynote*. Ávila, Spain. DOI: 10.5281/ZENODO.3384881.

Verhoeven, Geert Julien Joanna, Seta Štuhec, and Iztok Štuhec (7-02-2019). *Modelling building costs from 3D building models*. Bergamo, Italy. DOI: 10.5281/zenodo.2557762.

Wallner, Mario (27.02.2019). *Die Kreisgrabenanlage in der prähistorischen Fundzone Traxlergraben*. Benedek Kaserne, Bruckneudorf, Austria.

— (2.-3.April 2019). *Carnuntum - the main Roman town at the Donaulimes in Austria*. Krems.

Wuchterl, Günther and Georg Zotti (2.-3.April 2019). *Raising awareness on nocturnal light pollution around astronomical cultural heritage sites*. Krems.

Zotti, Georg (2.7. 2019). *4D Skyscape Simulation in Stellarium*. Lancaster, UK.

12.3 Media coverage

LBI ArchPro – Miscellaneous

- <https://invidis.de/2019/05/digital-signage-projekte-interaktive-wikinger-stele/>
- <https://www.noen.at/mistelbach/aeltstes-graeberfeld-spuren-der-vorfahren-in-kleinhadersdorf-poysdorf-fotos-archaeologie-eva-lenneis-162814417>
- https://www.kleinezeitung.at/steiermark/muerztal/5710780/Kulturschatz-der-Woche_Liegt-unter-der-Kirche-eine-uralte-Krypta
- <https://volksgruppen.orf.at/hrvati/stories/3021971/>
- Universum Magazin 10-11, print, November 2019 « Mythische Wikinger ».
- https://science.apa.at/rubrik/kultur_und_gesellschaft/Das_Geheimnis_der_tibetischen_Huegelgraeber/SCI_20191122_SCI39431352651828598
- TV coverage in Dobar dan Hrvati on ORF2, 1.12.2019 « Bodenradarvermessung um Kirche Parndorf/Pandorf »
- Kronenzeitung/Burgenland Morgen, print, 5.12.2019 « Schatzsuche mitten im Dorf » (Mülendorf)
- <https://www.derstandard.at/story/2000112473438/kaupang-die-verschwundenen-siedlungen-der-wikingerzeit>

Denmark

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- <http://www.oestkysten.dk/fhn.html>
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- <https://sn.dk/Koege/Borgring-kommer-i-selskab-med-Stonehenge/artikel/824663>
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- <https://www.forbes.com/sites/davidnikel/2019/03/25/historic-day-viking-ship-found-in-norways-oslofjord-region/#34d753084664>
- <https://www.geek.com/news/geo-radar-detects-viking-ship-buried-underground-in-norway-1779936/>
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- https://www.kleinezeitung.at/international/panorama/5601516/Nahe-Oslo_Archaeologen-entdecken-bestattetes-Wikingerschiff
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- <https://www.inquisitr.com/5359500/archaeologists-have-just-discovered-a-rare-and-historic-viking-ship-burial-in-norway/>
- <https://www.ucnews.in/news/GeoRadar-Detects-Viking-Ship-Buried-Underground-in-Norway/2693566062251627.html>
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- <https://www.foxnews.com/science/mysterious-1000-year-old-viking-ship-discovered>
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- <https://www.westernstarnews.com.au/news/1000-year-old-find-on-popular-island/3888824/>
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Excavation Velm

- <https://www.youtube.com/watch?v=tJE1WJoNCqI> (TV coverage on Niederösterreich Fernsehen N1)
- <https://www.youtube.com/watch?v=qbMGZTA88yw> (youtube-video on ArchaeoTube by the Dept. of Prehistory and Historical Archaeology, Vienna)
- ORF2, Studio2, 19.7.2019: open day at excavation Velm (with live interview on site)
- NÖN, print, 4.7.2019 („Open Door im Kreisgraben“)
- NÖN, print, 18.7.2019 („Shuttlebusse zum Velmer Kreisgraben“)
- NÖN, print, 25.7.2019 („Sensation unter dem Acker“)

Tibet

- <https://derstandard.at/2000105122366/Begraben-auf-dem-Dach-der-Welt>

Stonehenge Exhibition LWL

- http://www.dtoday.de/regionen/lokal-panorama_artikel,-Mit-High-Tech-in-die-Steinzeit-_arid,652556.html
- <http://www.owl-journal.de/mit-high-tech-in-die-steinzeit/>
- <https://inherne.net/stonehenge-kommt-nach-herne/>
- <https://www.wp.de/staedte/herne-wanne-eickel/stonehenge-bekommt-2021-eine-ausstellung-in-herne-id216924023.html>
- <http://www.informationsdienst.ruhr/aktuell/detail/archiv/2019/april/artikel/lwl-plant-grosse-stonehenge-schau-in-herne-1.html>
- <https://www.epd.de/regional/west/schwerpunkt/kultur/stonehenge-denkmal-kommt-nach-herne>
- https://www.archaeologie-online.de/blog/stonehenge-kommt-nach-herne-4254/?utm_source=dldr.it&utm_medium=facebook

Corvey

- <https://www.westfalen-blatt.de/OWL/Kreis-Hoexter/Hoexter/3994563-Archaeologen->

- untersuchen-Stadtwuestung-Corvey-Forschen-ohne-Bagger-und-Spaten
- <https://www.wn.de/Muensterland/3997518-Radarfahrzeug-am-Weltkulturerbe-Corvey-Archaeologische-Untersuchungen-ohne-Bagger-und-Spaten>
 - <https://www.azonline.de/Muensterland/3997518-Radarfahrzeug-am-Weltkulturerbe-Corvey-Archaeologische-Untersuchungen-ohne-Bagger-und-Spaten>
 - <https://www.tah.de/lokales/lokalmeldungen/news-single/mit-schrittgeschwindigkeit-in-die-vergangenheit-corveys.html>
 - http://www.dtoday.de/startseite/nachrichten_artikel,-Archaeologische-Untersuchungen-am-Weltkulturerbe-_arid,690255.html
 - <https://www.archaeologie-online.de/nachrichten/ohne-bagger-und-spaten-archaeologische-untersuchungen-am-weltkulturerbe-corvey-4446/>
 - https://www.nw.de/lokal/kreis_hoexter/hoexter/22584230_Wie-ein-Rasentraktor-in-Corveys-Vergangenheit-blickt.html
 - <http://www.owl-journal.de/archaeologische-untersuchungen-am-weltkulturerbe-corvey/>

13. Training and teaching (TRAIN)

Following the recommendation of the evaluation panel, the LBI ArchPro has set a focus on training and teaching. This training is divided into internal training for main and partner staff, and external training at graduate and postgraduate level in relation to national and international funding schemes. This specific training involves internships at the LBI ArchPro, with a full integration of the interns in ongoing research projects and case studies. In addition to the research conducted within the institute, members of the LBI ArchPro team have been active both nationally and internationally in academic teaching. LBI ArchPro staff continued with consultation activities as well as scientific reviews.

13.1 LBI ArchPro Academy Trainings Program

The LBI ArchPro possesses considerable expertise in the theory and practice of archaeological near-surface geophysics and remote sensing, as well as the interpretative mapping of large-scale high-resolution archaeological prospection data. A goal of the LBI ArchPro is to establish standards for archaeological prospection (AP), primarily for improved internal workflows and routines. These standards concern data acquisition, data processing, geophysical and archaeological data interpretation, and data archiving. Without well-documented and standardized workflows, traceability and reproducibility of gained results cannot be guaranteed. According to the Valetta treaty, non-invasive recording and analysis of archaeological heritage must be state-of-the-art. These aspects highlight the responsibility of the LBI ArchPro and its partners in documenting, applying and if possible developing best practice methodological approaches of AP.

To this purpose specific internal education and training courses shall be offered to staff and partners. These courses shall be part of an overall educational program named “LBI ArchPro Academy”, which is to be developed together with the partner organizations, and which shall be organized by the LBI ArchPro. This program shall also provide further guidance through specific training and internships. If successful, these courses provide the future potential to be opened to external participants as a postgraduate training programme. A respective academic scheme could be developed that includes these courses as well as university lectures already given by LBI ArchPro staff and partners.

Basic Modules

Module: Geophysical survey

Lectures held within this module will provide practical knowledge on geophysical archaeological prospection, including fieldwork routines, survey strategies, data processing and data visualization. The course does not replace in-depth geophysical studies, but aims to focus on practical aspects of state-of-the-art near-surface geophysical archaeological prospection and the acquisition of high-quality prospection data for archaeological prospection.

The theory of near-surface geophysical archaeological prospection methods will be covered, including basic physical concepts of magnetometry, electromagnetic measurements, earth resistance surveys, and ground penetrating radar measurements. This introduction is adjusted for participants from the field of humanities, i.e. archaeology and cultural heritage related studies. The module will provide basic information required for the understanding of common prospection methods (measurement principle, sensors, survey routines, basic data processing).

After completion, participants should be able to choose appropriate methods and recognize common errors in the data.

Course contents

- fieldwork procedures
- methods
- systems
- safety routines
- primary data processing and visualization
- quality control
- data archiving procedures
- problem solving
- basic reporting

Module: Geophysical data processing and visualization using ApSoft

To safeguard a high quality of the collected data, immediate quality control in the field is necessary, while specialist data processing is required to generate optimized results for subsequent data interpretation. This module focuses on the correct use of ApSoft (only for LBI ArchPro staff and partners), an in-house developed specialist software for the processing of geophysical prospection data. Different software versions exist for basic quality control in the field and subsequent specialist processing.

Module: GIS-based interpretative Mapping using ArcGIS and ArchaeoAnalyst

The archaeological and geophysical interpretation of prospection data is a multifaceted and interdisciplinary task. It requires great experience in different scientific disciplines and involves interdisciplinary teamwork. Each interpreter needs to train basic skills to guarantee effective teamwork and standardized, efficient interpretation routines.

Geographical Information systems (GIS), in particular ArcGIS by ESRI, provide a wide range of geospatial analysis and mapping tools. While most of them are relevant for archaeological prospection studies, some are essential for the interpretative mapping of archaeological data. This module aims to introduce/refresh basic knowledge of ArcGIS (e.g. coordinate systems, projections, transformations, basic project setup, cartographic tools) complemented by more specific tools needed for interpretative mapping (e.g. drawing tools, streaming tools, shape-files, ArcGIS-toolbox) such as the ArchaeoAnalyst.

The LBI ArchPro has developed the ArchaeoAnalyst toolbox as an extension to ArcGIS. ArchaeoAnalyst enables and supports the creation and loading of geodatabases (raster and feature classes), the semi-automated detection and extraction of anomalies likely to be caused by iron

objects, as well as pit-like structures in magnetic prospection data, and advanced interactive visualizations and animations of GPR depth-slices. During this course optimized workflows for interpretative mapping using the ArchaeoAnalyst will be trained and discussed.

Module: Image Fusion using TAIFU

The aim of this module is to explore different methods of image fusion and their benefits, as provided by the LBI ArchPro software TAIFU. Participants will gain fundamental understanding of the methods and tools involved.

Goals

- Understand the basic goals of image fusion;
- Understand the basics workflow in TAIFU;
- Understand advanced import and post-processing options in TAIFU;
- Get to know the most promising fusion algorithms;

Estimated duration

0.5-1 day

Module: Image Based Modelling

Goals

- Understand the theoretical basics of photography;
- Understand the theoretical basics of image-based modelling;
- Able to define IBM goals and compute all the necessary photographic parameters;
- Use the computed parameters to acquire proper IBM, goal-oriented photo sets;
- Practical IBM knowledge using Metashape.

Estimated duration

5 days

Module: GIS-based spatio-temporal analysis using HMC+

The basis of every landscape-archaeological interpretation of archaeological prospection data is the spatio-temporal analysis of detected anomalies in the data. For this purpose, the HMC+ software was developed by the LBI ArchPro and lately integrated with ArcGIS. Thus, the entire functionality provided by ArcGIS (e.g. least cost path, view-shed) can be combined with additional information from prospection data or excavations, representing “temporal” layers. This module will provide specific training regarding the use of HMC+ and ArcGIS.

13.2 University lectures

Table 13.1 lists the academic lectures and courses held by LBI ArchPro staff in 2019.

13.3 Summer schools/workshops

Table 13.2 lists the summer schools/workshops held by LBI ArchPro staff in 2019.

Wolfgang Neubauer	Summer 2019	060041 PR Lehrgrabung 2 Velm/NÖ (vierwöchig)
	Summer 2019	060106 PR Ausstellungsgestaltung – Techniken und Konzepte der Vermittlung
	Summer 2019	060095 SE Seminar Abschlussarbeit
	Winter 2019	060096 SE Seminar Abschlussarbeit
Immo Trinks	Summer 2019	314.545 Methoden der Grabungsdokumentation, Vermessungstechnik und archäologische Prospektion, University of Salzburg, with Lydia Berger and Hansjörg Ragg
	Summer 2019	LV 800780-0 VU Limnogeologie, University of Innsbruck, with Michael Strasser, Jean-Nicolas Haas, Karin Koinig, Bettina Sonntag and Josef Wanzenböck
	Winter 2019	060048 VO Einführung zu archäologischen Prospektionsmethoden
Michael Doneus	Summer 2019	060073 UE GIS-Anwendungen in der Archäologie
	Summer 2019	060075 VU Luftbildarchäologische Interpretation
	Summer 2019	060088 SE Prehistoric Landscapes of North America
	Summer 2019	060090 VU Vertiefende Übung zur wissenschaftlichen Praxis
	Summer 2019	060092 SE Seminar Abschlussarbeit
	Winter 2019	060061 UE GIS-Anwendungen in der Archäologie
	Winter 2019	060077 UE Flugzeuggetragenes Laserscanning (LiDAR) für ArchäologInnen
	Winter 2019	060087 VO Landschaftsarchäologie
	Winter 2019	060089 UE Vertiefende Übungen zur Luftbildarchäologie
Winter 2019	060092 SE Seminar Abschlussarbeit	
Klaus Löcker	Summer 2019	060069 UE Grundlagen archäologischer Stratigrafie
Geert Verhoeven	Winter 2019	060072 VU Image-based modelling for archaeology
Matthias Kucera	Winter 2019	060054 VO Experimentelle Archäologie
Georg Zotti	Winter 2019	060074 VO Einführung in die Archäoastronomie

Table 13.1: Academic lectures and courses held by LBI ArchPro staff at Vienna University, if not stated otherwise.

Geert Verhoeven	Summer 2019	Photography for 3D modelling of cultural heritage (CIPA summer school)
	Summer 2019	3D Survey Group – Politecnico di Milano: Summer school Laboratory of Places 2019 (Domodossola, Italy)
	Summer 2019	Remote Sensing (Royal Netherlands Institute in Rome)
	Winter 2019	The 3D datafication of cultural heritage: more than just a flash in the pan? (Invited lecture at HafenCity Universität Hamburg)

Table 13.2: Summer schools given by LBI ArchPro staff.

14. Case studies

14.1 Austria

Neolithic Monuments

Niederleis & Eggendorf

Short description of project: Contextualisation of neolithic ring ditch / Kreisgrabenanlage [KGA] monuments by magnetometry

Short description of site: Agriculturally used fields with loess soils in Lower Austria

Datasets: High-resolution magnetometry

Keywords: Neolithic Ring ditch monuments; surrounding environment

Benefits: Improved understanding of the KGAs within their environment and their relationship to neighbouring archaeological monuments

In 2019, the case study on Middle Neolithic circular ditch systems focused on two sites. The circular trench system in Niederleis had been discovered in aerial photographs and was investigated by geomagnetic prospection in the falls after harvesting. In both cases a magnetometer system consisting of 8 Förster FEREX probes mounted on a non-magnetic carriage and pulled by a quad was used. The double system, whose outer trench has a diameter of over 90 m and the inner one of about 60 m, has four entrances aligned with the directions of the compass. The maximum width of both trenches is about 6 m (Fig. 14.1). To the east of the circular trench is an area with numerous anomalies, which appear to be arranged in rows and are partially thermoremanently magnetized. West of the investigated site there are large anomalies (sampling pits?), which are commonly found in the vicinity of Middle Neolithic sites. In total, about 3 ha have been prospected on this site in one day.

The second circular ditch is located in the area of KG Eggendorf am Walde (Fig. 14.2). This site has been known since the first half of the 20th century. The special feature of the site is the continuity of the Linear Pottery and the following Middle Neolithic in combination with the exceptional quality of the old excavated finds from both periods, which were collected over the decades. Furthermore, a part of the site is located in a corridor called "Black Earth", this name may indicate a preserved original humus/transitional horizon, which could indicate an exceptional



Figure 14.1: Overview of the double circular ring ditch system of Niederleis with a diameter of over 90 m. Aerial photo: © geoland.at.



Figure 14.2: Overview of the areas surveyed at Eggendorf am Walde, covering 16 ha. The diameter of the circular ring ditch system is over 120 m. Aerial photo: © geoland.at.

preservation of features.

The existence of a circular ditch on this site was suspected by research. This assumption could already be confirmed on the first day after two hours. The site, which has been prospected to about 90% so far, is a triple circular ditch with four entrances aligned with the main cardinal points, only the northern entrance is turned about 15° to the west. The outermost trench seems not to have been completed in the east. It has a diameter of about 125 m, making it one of the largest known ditch systems in Lower Austria. The width of the trenches varies between about 6 meters in the innermost and outermost trench and 4 m in the inner trench, the width of the entrances between one meter in the south and 2.5 m in the east and west.

To the west of the circular ditch, there is a trapezoidal ditch, the northern end of which has for the most part not yet been prospected. The parts identified so far point to a construction of about 250 m by 210 m, with a width of the trench being up to 5 m. Elongated anomalies and linearly arranged pits are distributed over the area of this trench system and the circular trench, which can be interpreted as remains of accompanying trenches of Linear Pottery longhouses.

From the data collected so far the following Neolithic settlement activities can be reconstructed: a Linear Pottery settlement with several successive courtyards is separated from the surrounding area by a ditch in a further (second?) settlement phase. The Middle Neolithic circular ditch represents a third phase of Neolithic use of this site. Surface finds also prove a Bronze Age use of the area. In the southern part of the site towards a stream, anomalies are found which can be interpreted as pit houses and which indicate a further phase of use (Iron Age? Early History?). The prospection will be continued in 2020 to cover the entire extent of the Neolithic site.

Velm

Short description of project: Prospection and excavation of a Neolithic ring ditch / Kreisgrabenanlage [KGA] monument

Short description of site: In contrast to other KGAs, the KGA monument at Velm is located on gravel deposits instead of loess

Datasets: Magnetometry (Fluxgate and Cesium); GPR (MIRA and SPIDAR)

Keywords: KGA; settlement remains of Lengyel culture

Benefits: Very good GPR response due to the geological site conditions

Due to several years of research on the KGA-Velm using non-destructive methods, a research excavation was carried out to investigate two key areas of the Middle Neolithic site last summer. On the one hand, one of the presumably contemporaneous house structures in the direct vicinity of the KGA was selected and on the other hand, the stratification of the outer trench of the site was to be investigated.

The research excavation was carried out in collaboration with the University of Vienna and was scheduled for four weeks. In the course of the excavation the house structure was exposed completely and an almost perfect match with the GPR data was revealed. The excavated surfaces were documented by image based modelling and will be used for a detailed analysis of the non-destructive data sets. Also the internal structure of the outer ditch and the associated palisade could be explored in great detail and showed a high consistency with the geophysical prospection data.

On the basis of the finds, collected during the excavation, a dating into the Middle Neolithic Period is to be considered as certain; more precise dating using the C14 method is currently being carried out.

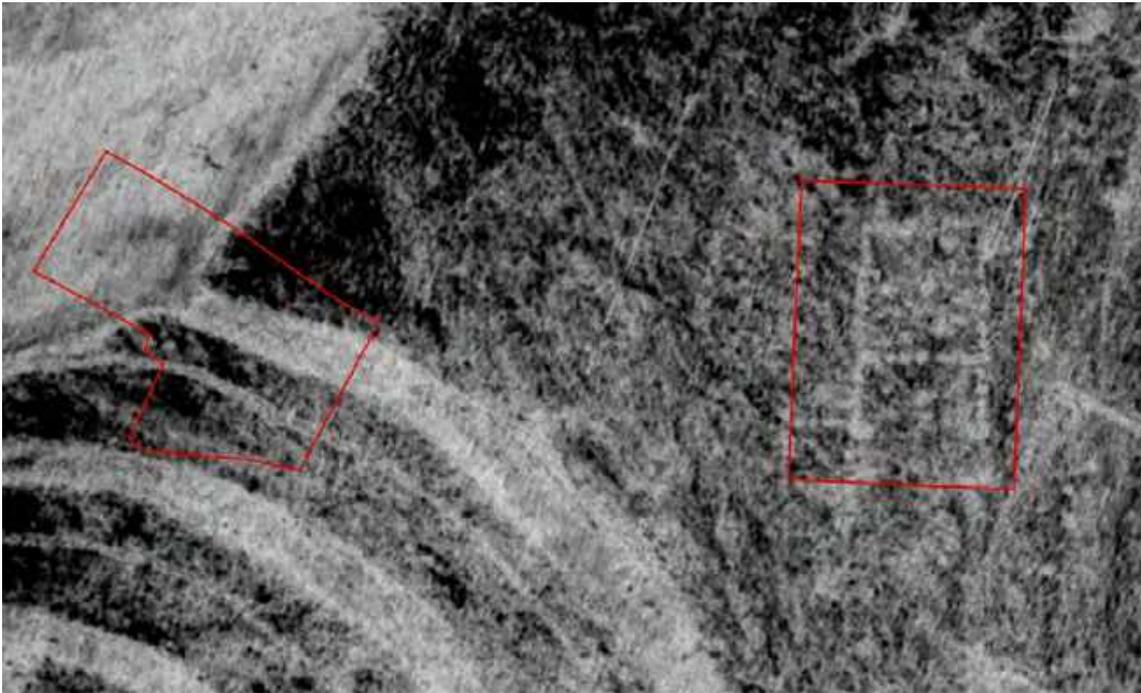


Figure 14.3: Excavation trench (red line) overlaying GPR-dataset (KGA-Velm).

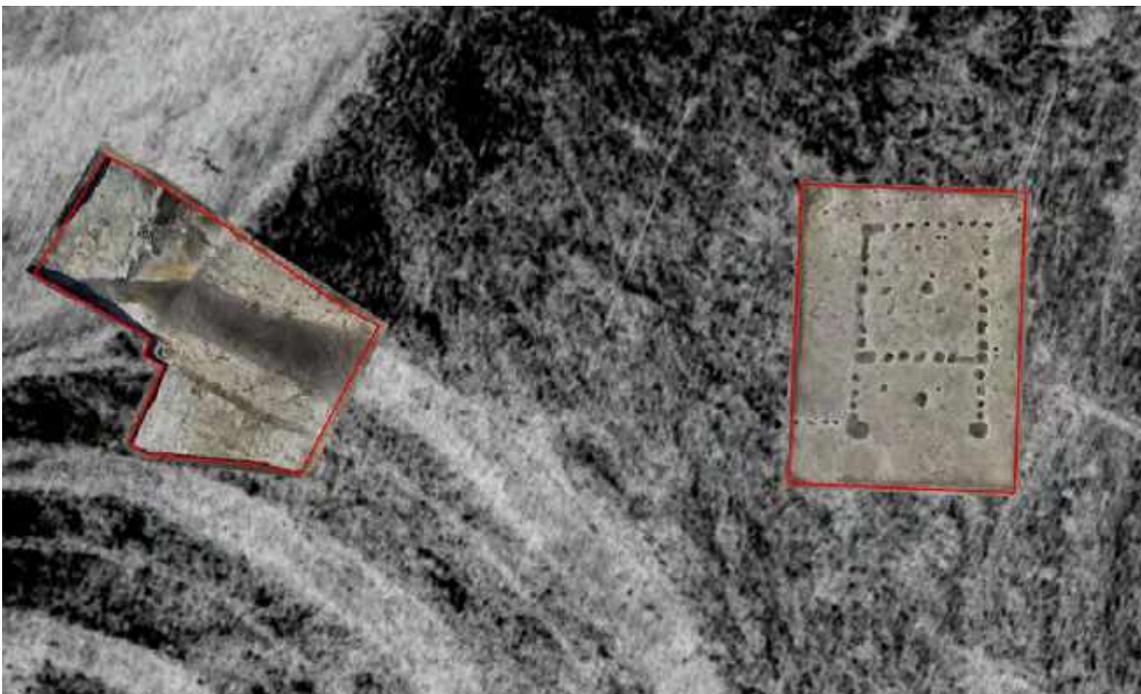


Figure 14.4: Excavation overlaying GPR-dataset (KGA-Velm).

Eisengraberamt – a medieval iron smelting site

Short description of project: Prospection and excavation of a likely medieval iron smelting site

Short description of site: Agriculturally used field with clayey soil in slope; indications for thermoremanently magnetised kiln structures; iron slag

Datasets: Fluxgate magnetometry; SPIDAR 500 MHz GPR; excavation

Keywords: Iron production site; multi-method investigation; follow-up excavation

Benefits: Enhanced understanding of correlation between prospected and excavated features

The possible iron smelting site in the community of Eisengraberamt could represent one of the earliest industrial sites of Austria. Historical sources document an iron ore quarry around the year 1150, which was administered by the nearby monastery of Zwettl. The site has been known for several years and was relatively well defined by means of field surveys, as a dense distribution of iron slag fragments can be recognized on the surface. Since these slag fragments and the expected furnaces are well visible in a magnetic survey, the entire field was investigated in early spring. Here it turned out that the spread of the iron slags was very sharply defined. In addition, a number of possible furnaces could also be located. Furthermore, the central area of the smelting place was explored by ground penetrating radar (SPIDAR 500 MHz). Unfortunately, the suspected structures were only partially visible in the GPR survey, probably due to the poor preservation conditions of the smelting furnaces. However, this observation could only be corroborated by the following research excavation.

Following the geophysical prospection in spring, parts of the iron smelting site were excavated during a two-week campaign in summer. The aim of the excavation was to verify the magnetic anomalies, to investigate the design of the possible furnaces and to obtain samples or finds for dating. This investigation was carried out as a public participation project. Hopes for rising furnaces were disappointed, as these appear to have been built entirely of clay and have been aberrantly eroded. The amount of kiln clay is also vanishingly small, but the number of nozzle fragments, on the other hand, suggests a high number of smelting processes. At the centre of the excavation were two pits from which the clay for the construction of the furnaces was probably taken and into which the slag and other waste was disposed of. Until scientific data is available, the site can only be dated to the High Middle Ages by means of a few pieces of pottery; the C14 dating is currently pending. This fits in with historical news from the years around 1150, when Zwettl Abbey in the area of the Eisengraberamt was enfeoffed with the exploitation of three limonite deposits by the Babenbergs. The Babenbergs acquired Styria in 1192 and thus had access to the ores of the Ore Mountain, which probably rendered the exploitation of the deposits in the Eisengraberamt area meaningless. In a further step, further known smelting sites, which probably belonged to the two other mines mentioned in the medieval sources, are to be geophysically prospected in 2020. The processing of the excavation results and the synthesis with the prospection results will be carried out within the framework of a student research project at the Institute for Prehistory and Historical Archaeology at the University of Vienna.



Figure 14.5: SPIDAR 500 MHz measurements at Eisengraberamt.

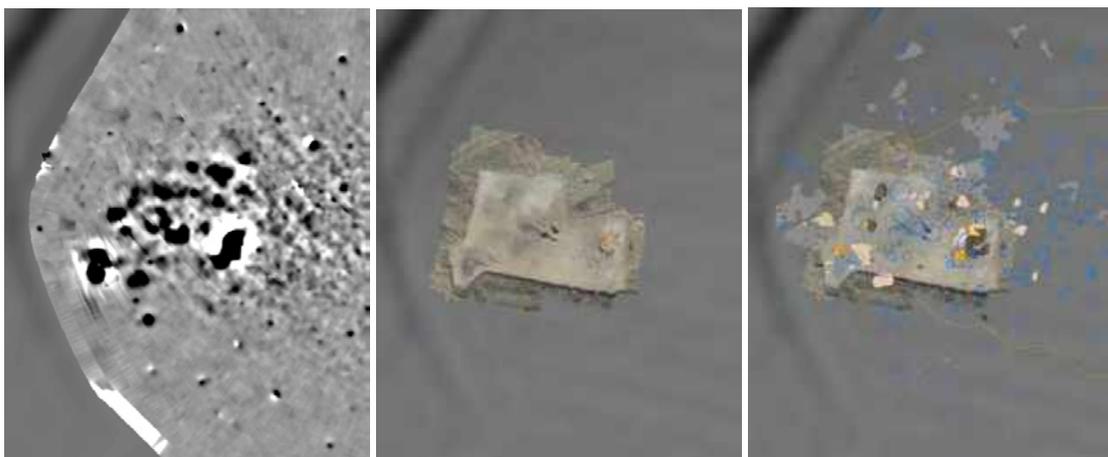


Figure 14.6: Eisengraberamt: Magnetic prospecting, excavation and combination of the iron smelting site.

Kleinhadersdorf

Short description of project: Investigation of the settlement remains belonging to one of the oldest cemeteries known in Austria

Short description of site: Linear Pottery Culture (LPC) remains located in agricultural field

Datasets: Fluxgate and Cesium magnetometry; LiDAR data;

Keywords: LPC; settlement remains and cemetery; magnetometry; future excavation planned

Benefits: Gaining a comprehensive understanding of one of the oldest Austrian LPC communities

The Linear Pottery Culture burial ground of Kleinhadersdorf was already discovered in 1931 and mostly excavated in the late 1980ies. It is the oldest known burial site in Austria. Due to this fact the LBI ArchPro has done a magnetic survey in the years 2017 and 2018. After a thorough interpretation of the collected data the results were presented to the public in September 2019. A long gone large settlement has become visible in the data right south of the early Neolithic graveyard. The houses seem very well preserved so that most of the inner post structures are still very well visible. This is due to the fact that the houses got protected by a depression right behind the hilltop in which the settlement was built in. This depression was as well one of the possible reasons the village got set up where its remains have been found. Another reason for the footing of the settlement was probably the nearby spring, that has dried up today but is still very well visible on the LIDAR scans of the plateau.

Due to the resonance of the presentation of the survey results, an excavation campaign will be realised in the summers of 2020 and 2021 to get a better view onto the data itself which will help calibrate the interpretation as well as date the settlement which is postulated to be used and build by the people buried in the nearby graveyard.

Rosenburg

Short description of project: Research Project with Riegl LMS

Short description of site: Medieval castle Rosenberg, Lower Austria

Datasets: GPR, TLS, historical sources

Keywords: Visualization and interpretation of GPR and TLS data, surveying castles

Benefits: Close cooperation with Riegl LMS to work on the implementation of GPR and TLS data, integrated interpretation of TLS and GPR data

The castle Rosenberg is located close to the Riegl LMS headquarters in Horn/ Lower Austria and is perfectly suited for a joint study. Huge open areas in the interior – in the outer bailey – were examined with GPR (MIRA 400 MHz) and TLS. Below this area cellars were also recorded applying TLS. Both datasets were combined, and the results already presented successfully at several conferences. The cooperation with Riegl LMS is of crucial importance for the LBI ArchPro and its partners, both regarding the development of cutting-edge recording techniques and technical support at other surveys (Peru, Svalbard).

The Bronze Age settlement Steinbach

Short description of project: Investigation of the settlement structure of a formerly Bronze Age, now Neolithic site

Short description of site: Agriculturally used fields on a loess ridge in Lower Austria

Datasets: Fluxgate magnetometry

Keywords: Enclosed Neolithic settlement

Benefits: Gaining the complete layout of an enclosed settlement site previously known only from aerial photography

The prospected site is located northeast of the village of Steinbach in the Weinviertel not far from the Oberleiser Berg. It was discovered by aerial photo prospection in the second half of the 20th century and dated by means of collections mainly in the Bronze Age and Urnfield Period, with a beginning in the Middle Neolithic. The motivation for prospecting this site is the complete prospection of a fortified prehistoric/Bronze Age settlement that was hardly ever reused or built over. During two days about 19 ha were explored by geomagnetic prospection. A magnetometer system consisting of 8 Förster Ferex probes was used. They are mounted in a distance of 25 cm on a non-magnetic cart pulled by a quad, the positioning is done by a GNSS RTK system. The most striking finding was the trench surrounding the settlement. It has a total length of about 1.2 km and covers an area of about 10.1 ha. Several entrances/earth bridges are visible. In the west, the topographically easiest access to the site, the moat was probably once moved back to the interior, creating a kind of access area. Within the moat, several old pathways can be identified, some of which correspond to the earthen bridges, while others run across the moat. The development is dense, only in the northern area, on the slope towards the Nodenbach, the steepest area, the anomalies thin out. In this first step, primarily the area bordered by the moat from the surrounding area was prospected. Subsequently, the surrounding areas are to be investigated as well, in order to be able to place the find site in a broader context.



Figure 14.7: The so far prospected area of the prehistoric settlement of Steinbach covers approximately 20 hectares.

Frein – snow survey

Short description of project: Research project LBI ArchPro

Short description of aims: Analysis of relation between snow cover characteristics and GPR penetration depth of soil.

Datasets: GPR (single channel, 1000 MHz, 500 MHz, 250 MHz), Snow profile

Keywords: GPR on snow; layers of snow; avalanches

Benefits: Future optimization of survey planning during wintertime and snow cover

The focus within this project is set on the possible resolution of different layers inside the snow cover. It aims to detect zones of instability inside the snow cover to gain further knowledge of the formation and transformation processes of snow. Furthermore, it investigates the dependency of the consistency of snow (dry snow, frozen surfaces, humidity, wet or dry soil surface) and the penetration of the GPR pulse into the soil. Two single channel surveys were undertaken in Frein/Styria. The aim of the first survey was to test different frequencies regarding resolution in the snow cover. The overall snow depth was about 1.8 to 2 m. For the purpose of resolving different snow layers 500 MHz and 1000 MHz were promising. During a second survey, frozen traces and zones of instability could be observed inside the snow. Although the snow and the top surface of the soil were extremely humid, good penetration into the soil could be observed. This basic research is very important for future survey planning during wintertime to optimize results during archaeological prospection.



Figure 14.8: Test of 500 MHz and 1000 MHz single channel antennae on thick snow cover.

14.2 Germany

The medieval town of Corvey, Höxter

Short description of project: Prospection of the medieval deserted village of Corvey

Short description of site: Site of an old sawmill, presenting the centre of the medieval settlement

Datasets: Fluxgate magnetometry and MIRA I GPR

Keywords: Medieval settlement, UNESCO World Heritage Site

Benefits: Localisation of the old church and investigation of settlement structure in collaboration with partner LWL

Among the medieval deserted towns in Central Europe, Corvey has a special status being the largest. In the 13th century, the town lost its importance due to rivalry with the neighbouring town of Höxter and was abandoned after a terrible fire. In October 2019, high-resolution ground penetrating radar and magnetic measurements were conducted in the area of the deserted medieval town of Corvey. During the first campaign, the ground plan of the so-called 'Marktkirche' was recorded in highest detail for the first time. This three-nave basilica with a single tower was considerably smaller and simpler than previously assumed and can be dated to the late 12th century based on the results of an excavation in the 1980s.



Figure 14.9: Magnetic prospection at the deserted medieval town of Corvey.

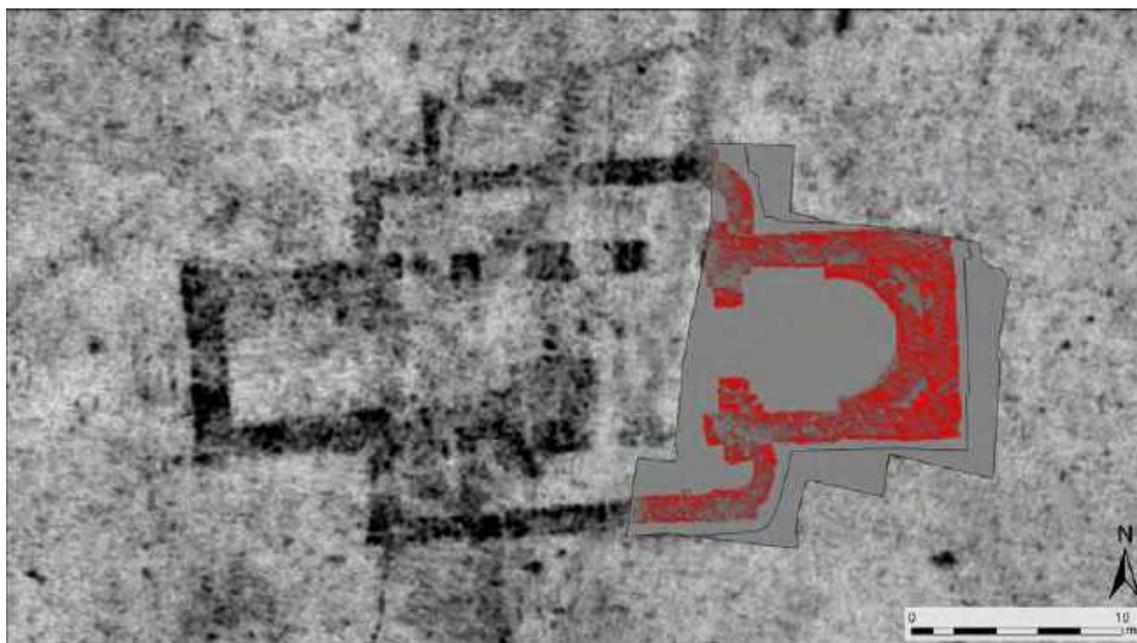


Figure 14.10: GPR dataset of the 'Marktkirche' combined with excavated area (in red).

14.3 Peru

Chachapoyas

Short description of project: Research project LBI ArchPro in cooperation with Brown University/Boston/USA

Short description of sites: Pre-Columbian sites in Peru, Main site of the Chachapoya (Warriors of the clouds) in Kuelap, smaller sites Santa Martha and El Koral

Datasets: UAV based ALS, TLS, IBM

Keywords: Remote areas, combination of ALS, TLS and IBM, vegetation cover, survey strategy

Benefits: First survey of the LBI ArchPro in South America, future cooperation with partners in USA and Peru, showcase for further surveying and monitoring of cultural heritage in Peru and the Americas

The Chachapoya region is part of Amazonia, one of the counties of Peru. The recording and documentation of archaeological sites in this area is a challenge regarding logistics, survey strategies and the processing of the data. Some of the sites are only reachable in a week's horseback ride. The LBI ArchPro was recommended to Brown University in Boston/ USA to do a joint survey. The present survey campaign was a first test to check the applicability of the survey routines of the LBI ArchPro. Because of some custom difficulties it was necessary to rent a Laserscanner in Lima/ Peru. Riegl LMS provided a contact, which enabled the LBI ArchPro to rent a Laserscanner from a Riegl LMS subcontractor and reseller company (Cotecmi). For this survey a Riegl VZ2000 with one battery lasting for 5 hours was at hand.

The collected TLS data is combined with ALS data gained by an UAV survey (using a VUX) earlier and more recent photo drone IBM data. The recording of cultural heritage plays a very important role in Peru, as the monuments are under constant threat through erosion and flooding but also through mass tourism, as it is observable in Machu Picchu. The processed data is an excellent testing dataset of the possibilities of combined TLS and IBM surveys in the respective area under the given circumstances. It suits perfectly as a showcase to illustrate the benefits of



Figure 14.11: Mr. Parker VanValkenburgh (center) and Matthias Kucera with a VZ2000 in front of Kuelap/ Peru.

further collaborations.

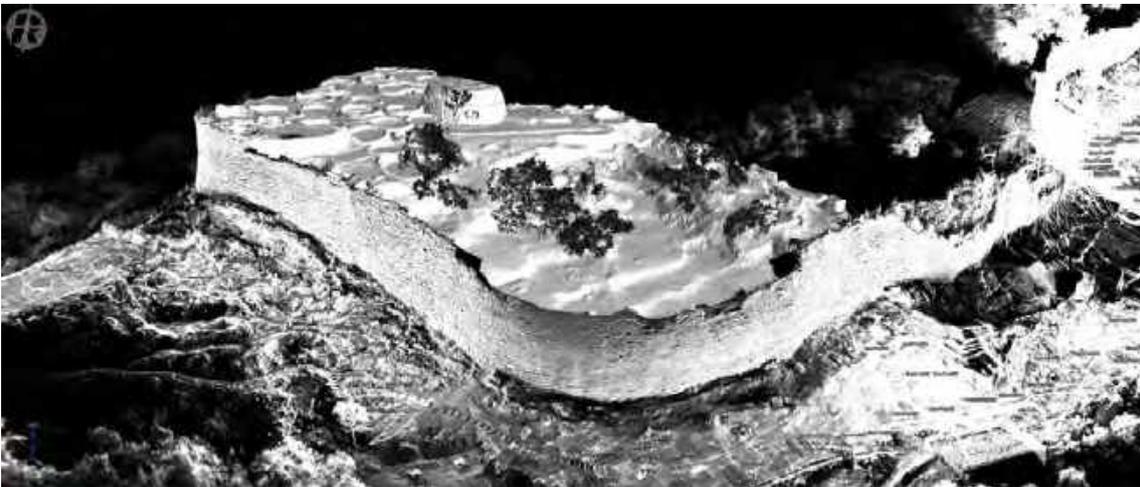


Figure 14.12: Combined model of Kuleap – ALS (UAV with VUX) and TLS (VZ2000).

15. Third party funded research

15.1 Austria

Gars

Short description of project: Third party funded project (County of Lower Austria) at two sites in and close to Gars am Kamp, Lower Austria.

Short description of the site: Medieval castle and early medieval fortified hilltop settlement (Slavic), Urnfield Period (UK) rampart, grave mounds, cemetery, early medieval church/chapel.

Datasets: GPR, IBM, ALS, TLS, excavation

Keywords: Combination of TLS and ALS, surface reconstruction, survey strategy, dissemination and PR.

Benefits: Close collaboration with Riegl LMS, testing of i-series terrestrial Laserscanners, introduction of UAV based ALS (Ricopter and VUX), best practice TLS and ALS combination.

The project started in early 2019 by introducing UAV based ALS at a case study in Austria for the first time. The project combines TLS, ALS, IBM, GPR and magnetic prospection to analyse especially the spatio-temporal development of the fortified hilltop settlement with underlying UK ramparts. The project has major importance regarding the good cooperation between Riegl LMS and LBI ArchPro. The good relationship with Riegl LMS led also to great support during the Svalbard/ Svea survey and the Peru survey.

Regarding scientific questions and methodological basic research, the combination of recent topographic information (TLS, ALS), excavation data and GPR data will focus on the reconstruction of the specific temporal appearance of the landscape. The surface will be remodeled based on the single datasets. A further challenge is the GPR and magnetic prospection surveys themselves, as the area is mostly forested. Post processed GNSS RTK is tested regarding its accuracy and effectiveness depending on the vegetation cover.

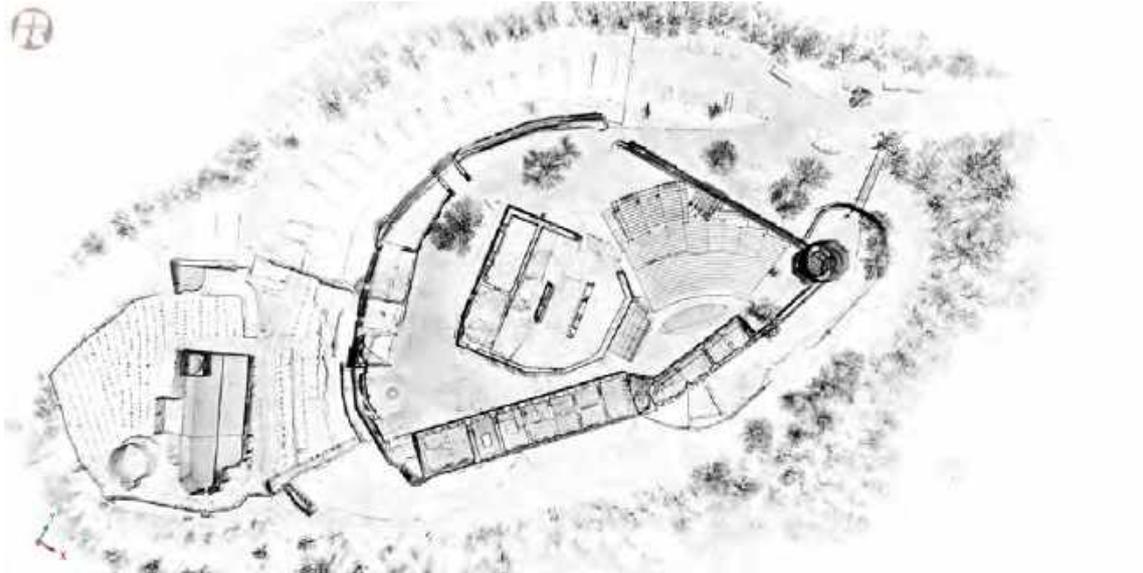


Figure 15.1: TLS data of the castle in Gars am Kamp. 800 Scan positions have been recorded during 3 days.

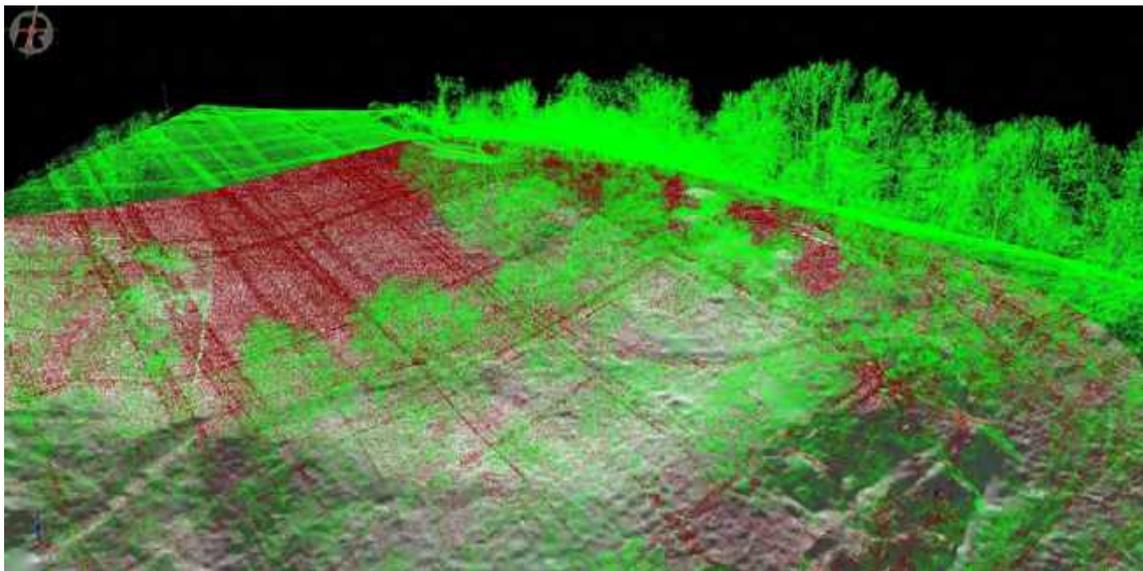


Figure 15.2: UAV based ALS data (VUX) from the fortified hilltop settlement in Gars. Vegetation (green) is filtered.

Staatz

Short description of project: Third party funded project (Gemeinde Staatz, Lower Austria)

Short description of site: Several wine cellars in Staatz, Lower Austria, which are located below a small road. The aim is to determine the exact location of the cellars in respect to the road level to investigate possible instabilities.

Datasets: GPR, TLS

Keywords: TLS survey strategy, combination of GPR and TLS, topographical correction based on TLS

Benefits: Display of GPR and TLS data in the same viewer, visualization of cavities in GPR data, basic methodological research regarding the appearance of cavities in GPR data

During three survey campaigns the area of interest was 3D recorded applying TLS. For this purpose, the recently developed survey strategies for more effective TLS recording were tested. All scan positions with enough GNSS signal were aligned without the use of control points. Only three core positions were used to georeference the whole projects. For the alignment of the scan positions taken in the cellars, control points were used. To speed up the survey, these control points were not register globally using a totalstation as usual. These scans were aligned with the georeferenced scans from the outside. With this strategy, 210 scan positions with a resolution of 60 mdeg could be recorded in one day. Additionally, the road above the cellars was examined with GPR (SPIDAR 250 MHz, and single channel 160 MHz). This was done to detect possible further so far unknown cavities, which could cause instability of the road. TLS data and GPR data were interpreted and visualized in one viewer. RiscanPro supports the import of GPR data with indicating the reflectivity. Changes of the pavement of the road, which could indicate the location of the drainage system and manholes where marked in the TLS data to compare it with the GPR results.

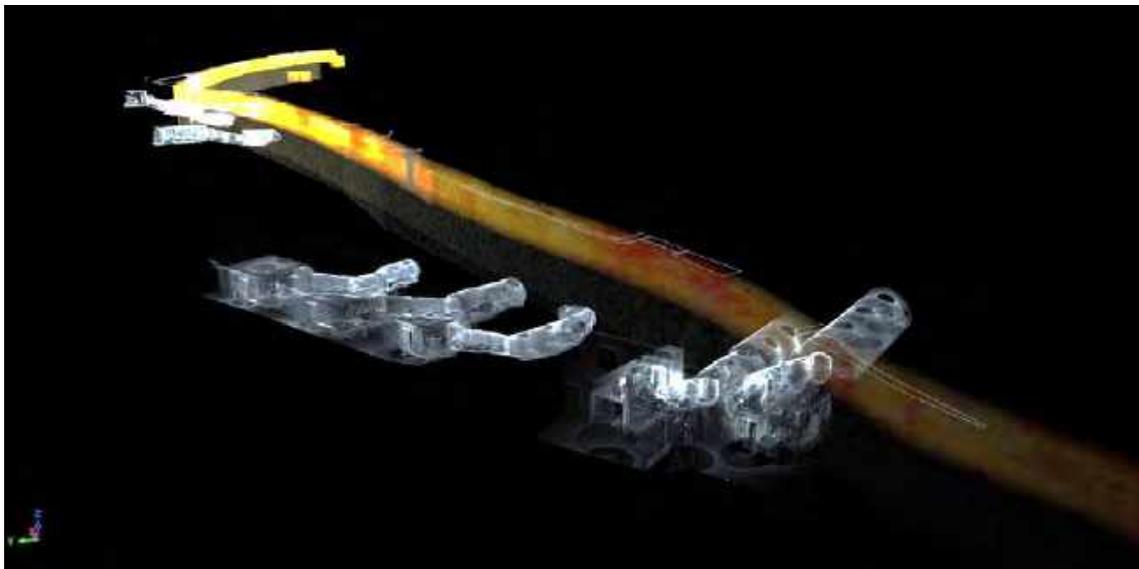


Figure 15.3: Staatz: Several wine cellars are located below or close to a road. The GPR data is visualized as a point cloud in RiscanPRO 2.8. The polygons on the surface indicate zones of different pavement extracted from the TLS data.

15.2 Bulgaria

Pliska

Short description of project: Large-scale investigation of the first early medieval capital of Bulgaria

Short description of site: early Medieval city located in agriculturally used fields

Datasets: Fluxgate magnetometry; SPIDAR and MIRA II GPR

Keywords: Extensive early medieval city, buried wall structures

Benefits: Investigation of one of the largest early medieval cities openly accessible for archaeological prospection methods

Between 2016 and 2018, two large-scale geophysical survey campaigns were conducted at Pliska, the first early medieval capital of Bulgaria (7th – 11th century AD). The surveys were conducted using a motorized Fluxgate magnetometer system as well as a motorized 250 MHz GPR array, leading to countless newly discovered structures in the city centre, as well as several semi-urban settlements within the surveyed areas of the vast Outer City of Pliska. The aim was to document yet unknown archaeological remains to achieve a better understanding of the urban layout and the successive construction phases of the entire settlement. The results lead to a more detailed understanding and depiction of the historical development of the Inner City during its capital- and post-capital phases of use, while the data collected in the Outer City improved the knowledge of the complex landscape of this area, extending over several square kilometres. In 2019, the collected data and integrated interpretation results were published via the Open Access “Bulgarian e-Journal of Archaeology” (<https://be-ja.org/index.php/Be-JA/article/view/216/196>)



Figure 15.4: Magnetic (red) and GPR (blue) survey areas at Pliska.

15.3 Denmark

Bornholm – Sorte Muld

Short description of project: High-resolution archaeological prospection of an outstanding Iron Age central place on Bornholm

Short description of site: Black Earth environment in agriculturally used fields, comprising building remains in form of pits, postholes, small trenches

Datasets: MIRA II and SPIDAR 500 MHz GPR, Fluxgate Magnetometry

Keywords: Iron Age; Viking Age; central place; high-resolution mapping; follow-up excavation

Benefits: Collaboration with Danish Iron Age experts on Bornholm and learning about the structure of one of the most outstanding Iron Age ceremonial places in Scandinavia

In April and September 2019, two short fieldwork campaigns were conducted at the Scandinavian Iron Age site of Sorte Muld on the Danish island of Bornholm. Between approximately 700 BC and 850 AD a centre of power had been located southwest of the modern small coastal town of Svaneke, as indicated by rich metal detector finds in form of over 2,500 gold foil figures – so called *Guldgubber* – made in an area of distinct Black Earth (dan. *Sorte Muld*) and nearby settlement remains found in the surroundings. A first successful magnetometry survey and small-scale GPR test measurements conducted by the archaeological prospection team of Kiel University (Christina Klein) in 2010 had indicated that the central area, where most gold finds had been made, appeared to have been surrounded by a trench.

The first extensive high-resolution GPR survey conducted by the LBI ArchPro on behalf of head archaeologist Finn Ole Nielsen of Bornholm Museum in April 2019 resulted in the detailed mapping of the central, so-called *temple area*, which had been enclosed by a dense row of posts that formed a fence or palisade, as indicated by numerous by GPR mapped postholes. Besides this enclosure, building remains inside and outside of the enclosure as well as a large number of pits were mapped in the central Sorte Muld area. The prospection results have guided an excavation conducted by Bornholm Museum in May, which showed very good agreement between the prospected and interpreted structures and the excavated features. A second successful fieldwork campaign was conducted in September 2019, mapping buried archaeological remains in further areas surrounding Sorte Muld (Fig. 15.5).



Figure 15.5: GPR coverage 2019 at Sorte Muld on Bornholm.

Odense – Nonnebakken

Short description of project: Prospecting VCiking Age ring fortresses

Short description of site: Viking Age ringfortress located in urban environment

Datasets: Manual GPR (500 MHz); MIRA I

Keywords: Archaeological prospection survey in challenging urban environment; Viking Age; ring fortress

Benefits: Test of prospection in urban environment; collaboration with Danish partner, the Museum in Odense

In spring and again in autumn of 2019, surveys were conducted, applying motorised and manual GPR systems, at the Viking Age ringfortress Nonnebakken. Nonnebakken is the only Danish ringfortress which lies within the downtown area of a modern City, namely Odense the capital of the Danish island of Funen. This complicated the surveys immensely, as there are very few open areas left between the buildings and streets of Odense, built over the Viking Age fortress. However, all accessible areas were investigated and the geophysical data collected by the LBI ArchPro showed clear evidence of the former fortress. This included the rampart and ditch, as well as several post built structures and pathways and possibly even the northern gate.



Figure 15.6: GPR survey areas at Odense – Nonnebakken.

Fyrkat

Short description of project: Prospecting Viking Age ring fortresses

Short description of site: Well preserved ring fortress, covered by grass

Datasets: MIRA I and SPIDAR GPR

Keywords: Archaeological prospection of Viking Age; ring fortress

Benefits: Collaboration with archaeologist Mads Runge of Odense Bys Museer

In spring of 2019, surveys were conducted at the Viking Age ringfortress Fyrkat, in the north of the Danish peninsula of Jutland, applying high-resolution GPR. More than 3.2 ha of GPR could be measured, documenting countless archaeological structures in and around the fortress. Fyrkat has an inner diameter of about 120 m and a more than 10 m wide rampart, partly surrounded by a 7.5 m wide ditch. It was excavated from 1950 to 1973 and is suspected to have harboured 16 internal Trelleborg-style longhouses organised in four quadrants. The geophysical data collected by the LBI ArchPro at Fyrkat shows signs of different settlement activities, graveyards and even archaeological structures possibly related to maritime transport.



Figure 15.7: GPR survey area at Fyrkat.

Aggersborg

Short description of project: Prospecting Viking Age ring fortresses

Short description of site: well preserved ring fortress, covered by grass

Datasets: MIRA I and SPIDAR GPR

Keywords: Archaeological prospection of Viking Age; ring fortress

Benefits: Collaboration with archaeologist Mads Runge of Odense Bys Museer

In spring of 2019, surveys were conducted in and around the Viking Age ringfortress Aggersborg, in the north of the Danish peninsula of Jutland, applying high-resolution GPR. Almost 9 ha of GPR could be measured, documenting countless archaeological structures. With a diameter of 240 m, Aggersborg is the largest of all Viking Age ringfortresses. It was excavated mainly between 1945 and 1952, although there have been targeted excavations until recent years. During excavations, the existence of internal Trelleborg-style longhouses as well as their characteristically planned layout in four quadrants could be documented. Unlike Trelleborg and Fyrkat, there was not one courtyard found in each quadrant of Aggersborg but three, amounting to 48 internal long-houses in total. The geophysical data collected at Aggersborg by the LBI ArchPro, however, mainly was able to document settlement structures prior and after the actual period of use of the fortress, which was only a few decades. This is of great use for future research, underlining the importance of the locality, already before and after the erection of the fortress during the reign of Harald Bluetooth.

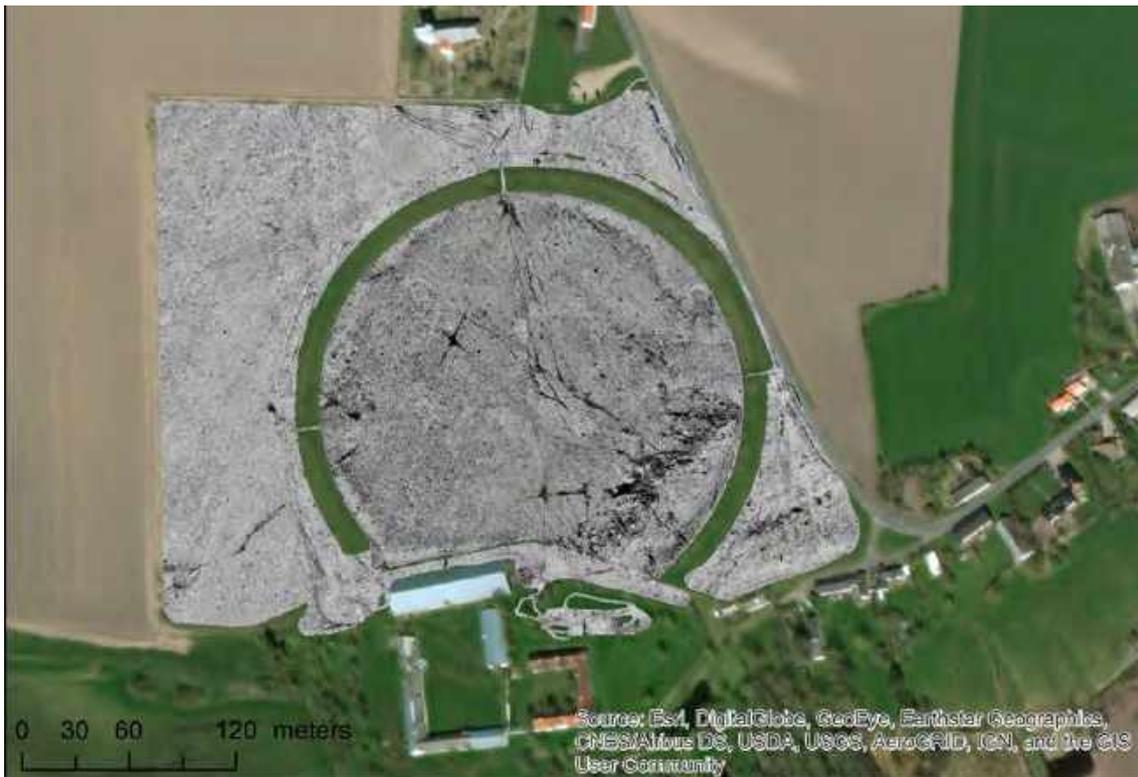


Figure 15.8: GPR survey area at Aggersborg.

Borgring

Short description of project: Prospecting Viking Age ring fortresses

Short description of site: Recently discovered ring fortress, flat grassland

Datasets: Fluxgate magnetometry, MIRA II GPR

Keywords: Archaeological prospection of Viking Age; ring fortress

Benefits: Collaboration with archaeologist Mads Runge of Odense Bys Museer

In spring of 2019, surveys were conducted in and around the recently discovered Viking Age ringfortress Borgring, in the east of the Danish island of Zealand, applying high-resolution GPR. Almost 0.5 ha of GPR could be measured, documenting possible archaeological structures. After its discovery in 2013 by ALS data, Borgring was investigated with geomagnetics. Based on the magnetic data from 2013, targeted excavations were conducted in 2014, proving a construction and shape of the rampart and gates characteristic for these ringfortresses. Furthermore, wooden remains were found, dating to the 10th or 11th century. Borgring has a diameter of about 120 m and a rampart of about 10 m width. Internal longhouses have not been discovered so far, which is why it was discussed, whether the fortress might have never been finished. The newly collected geophysical data of the LBI ArchPro can be seen as important addition to the excavations, documenting formerly unknown Iron Age settlement structures within the fortress.



Figure 15.9: GPR survey area at Borgring.

Ærø

Short description of project: Prospection of a assumed Viking Age trading place

Short description of site: Coastal site on agricultural fields

Datasets: Fluxgate magnetometry; MIRA I and SPIDAR 500 MHz GPR

Keywords: Viking Age settlement remains

Benefits: Collaboration with archaeologist Jesper Hansen of Odense Bys Museer

In autumn of 2019, surveys were conducted at Havsmarken, on the eastern coast of the Danish island of Ærø, applying GPR and magnetics. More than 10 ha of magnetics respectively of GPR could be measured, leading to the discovery of many archaeological structures such as possible cooking pits or pithouses. It was suspected by local archaeologists, that here at Havsmarken, an important maritime trading place was situated during the Viking Age. The geophysical data collected by the LBI ArchPro corroborates this assumption.



Figure 15.10: Survey area at Ærø, magnetics left, GPR right.

Vester Kærby

Short description of project: Prospection of a assumed Viking Age trading place

Short description of site: Agriculturally used fields

Datasets: Fluxgate magnetometry; MIRA I and SPIDAR 500 MHz GPR

Keywords: Viking Age settlement remains

Benefits: Collaboration with archaeologist Jesper Hansen of Odense Bys Museer

In autumn of 2019, surveys were conducted at Vester Kærby, on the Danish island of Funen northeast of Odense, applying GPR and magnetics. Around 17 ha of magnetics could be measured as well as more than 9 ha of GPR, documenting countless archaeological structures. Archaeologists assume, that here at Vester Kærby, close to the northern coast of Funen, another important maritime trading place was situated during the Viking Age. The geophysical data collected by the LBI ArchPro was able to define hotspots of possible past trading activity and furthermore gave important additional information regarding the interaction of settlement activity with geological and environmental preconditions.

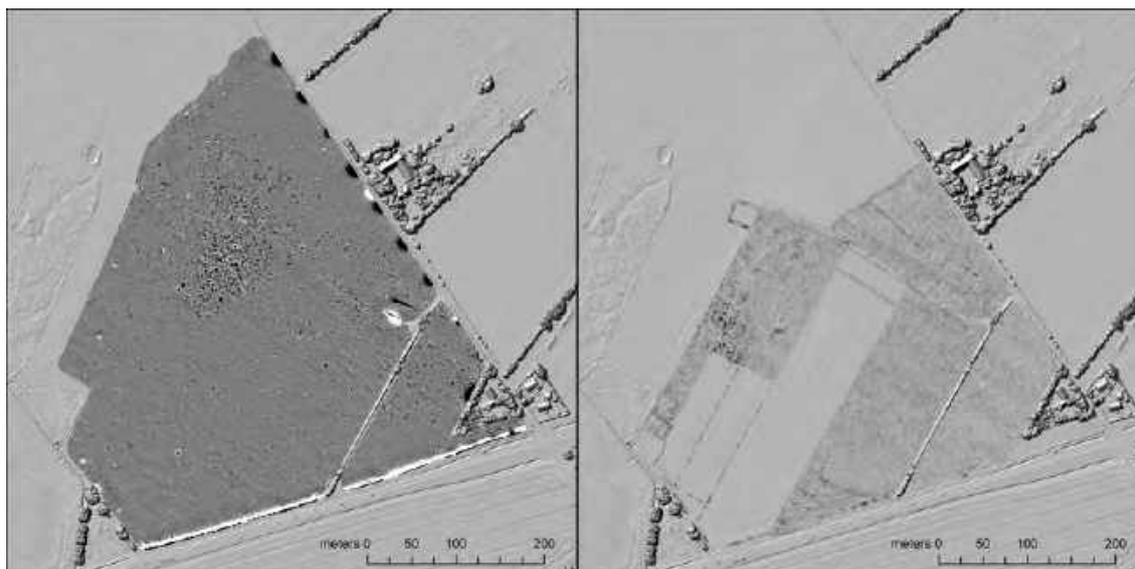


Figure 15.11: Survey area at Vester Kærby, magnetics left, GPR right.

15.4 Greece

Lousoi

Short description of project: Prospecting the urban structure of Hellenistic Lousoi

Short description of site: Mediterranean fields and fallow land, partly rough topography

Datasets: SPIDAR 500 MHz and 250 MHz and MIRA II GPR, Fluxgate magnetometry

Keywords: Urban structure and development; Hellenistic

Benefits: Collaboration with the Greek office of the Austrian Archaeological Institute in the framework of a FWF Research Project headed by PI Christoph Baier

As part of the FWF-funded project "The Urban Structure of Hellenistic Lousoi" (P 31801-G25), non-invasive studies of the settlement structure were started in 2019 on the basis of the preparatory work already carried out. Based on the knowledge gained in a pilot campaign in 2017, geophysical archaeological prospection measurements were carried out in a ten-day measurement campaign in the area north and east of the public centre of the Hellenistic Polis by the LBI ArchPro in cooperation with the ZAMG. On the extensive settlement terraces of this urban area, motorized measurements with geomagnetic and ground radar systems (400 MHz and 250 MHz) were carried out on a total area of about six hectares each. The combined analysis of the new prospection results as well as the findings from the 2016 architectural survey and the microtopography of the settlement area provides for the first time substantial insights into the regional planning and building density of the hitherto unexplored districts north and northeast of the Hellenistic city centre. In addition, more detailed information on the character of individual buildings was also obtained.

Of central interest is the now gained clear insight that the buildings north of the city centre do not follow a uniform regular development scheme. Nevertheless, the city was by no means planlessly laid out, as the alignments of the structures surveyed by prospection in the newly investigated urban areas testify. In different zones, they take up different orientation systems, which in turn are also found in the area of the city centre, where they seem to correspond to different stages of development. It is to be hoped that further prospectations in the urban areas not yet investigated will help to clarify the obviously complex internal relationships within the urban fabric.

For our understanding of the urban structure it is also of great interest that a large area immediately north and northeast of the Hellenistic city centre was apparently almost completely free



Figure 15.12: Challenging GPR survey conditions in Lousoi in June 2019.

of permanent buildings, as shown by the geophysical results. In contrast to this, the rather large terraces to the north of the city, which extend to the west and southwest below the Vetellino spring, were relatively densely built up. The conclusion is that the uncomplicated supply of these areas with fresh water was the decisive reason for the concentration of the buildings in the areas near the spring. For the supply of the public centre of the Hellenistic city further away from the spring, an elongated building in north-south orientation could have been of importance, which the geophysical measurements indicate almost 100 m east of the city centre. The apparently axially symmetrical design of this building and its isolated location below a terrain road leading to the Vetellino spring, on which the remains of a mortared water conduit have been preserved, suggest a possible function as a well house near the city centre.

15.5 Liechtenstein

Triesen

Short description of project: Prospection of Roman road and Bronze Age settlement remains

Short description of site: Small areas within a modern settlement, covered with grass, that subsequently have been excavated

Datasets: Fluxgate magnetometry, manual GPR and SPIDAR 500 MHz GPR

Keywords: Urban prospection of limited areas in order to see the wider picture

Benefits: Collaboration with the Antiquities and Monuments office of Liechtenstein; comparison of prospection with excavation results

The modern town of Triesen lies on the eastern flanks of the mountains accompanying the river Rhine and was inhabited since the Middle Ages. However, the goal of a joint research project between the LBI ArchPro and the Antiquities and Monuments Office was to find an old Roman road that supposedly led through this area about 2000 years ago.

Parts of the area that was measured by the LBI ArchPro using GPR in autumn 2018 were excavated by the archaeology department of the Principality of Liechtenstein. A comparison between the results of the archaeological excavation and the prospection results showed a clear

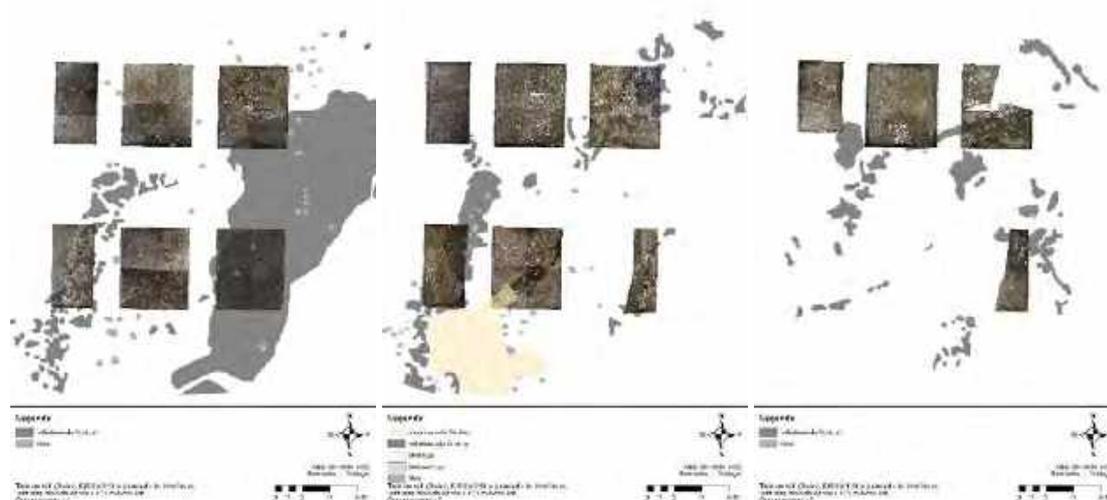


Figure 15.13: Triesen: Left: GPR depth-slice interpretation 0.20-0.40 m and excavation Planum 1. Centre: GPR depth-slice interpretation 0.40-0.60 m and excavation Planum 2. Right: GPR depth-slice interpretation 0.80-1.00 m and excavation Planum 3.

overlap, allowing to pinpoint the reflecting GPR structures onto actual stones, permitting a better interpretation and the attribution of specific GPR structures. Due to the low contrast in the GPR data, its interpretation was not trivial.

15.6 Norway

Svalbard – Svea

Short description of project: Third party funded project (Norske Kulkompani) run by NIKU

Short description of site: Coal mining area, industrial site in Svea / Svalbard/ Norway

Datasets: TLS, UAV based IBM, IBM

Keywords: Remote areas, industrial 3D recording, RealityCapture, high resolution big data

Benefits: Optimization of survey strategies, application of RealityCapture, combination of high-resolution IBM and TLS data

Based on the survey routines developed and tested earlier this year the NIKU team was supported by the LBI ArchPro core staff members with a VZ400 and a rent VZ2000i Riegl LMS Laserscanner. The strategy was based on the results gained by the close collaboration with Riegl LMS in Gars. During the campaign minor problems with the scanners were solved remotely by the Riegl LMS support team.

A multidisciplinary team of 12 researchers operated three terrestrial Laserscanners (two VZ400 and one VZ2000i), six full format SLR cameras (Nikon and Canon), two drones (DJI Inspire II), eight Laptops, one server PC and one NAS-server as storage device. 17 Terabyte of rawdata were collected summarizing 3,500 scan positions and 170,000 photos. In addition, terrain models and aerial images, historic aerial images and drone photos from SNSK were used.

For processing and visualization, the software RealityCapture was used, which allows to combine IBM and TLS data in a most convenient way. The project is a milestone regarding the amount of data collected, its high-resolution quality and the processing and visualization strategies. It is a marvelous showcase for future collaborations and highlights the opportunities for further large scale surveying projects.



Figure 15.14: Lisa Aldrian, armed, and a VZ2000i at Cape Amsterdam in Svea.



Figure 15.15: Svea: Industrial remains visualized through a combination of TLS and IBM data in RealityCapture.

15.7 Serbia

Glac

Short description of project: Prospection of a Roman imperial building complex

Short description of site: Agriculturally used fields

Datasets: MIRA I GPR

Keywords: High-resolution GPR; rich Roman architectural remains

Benefits: Collaboration with local partner Stefan Pop-Lazić

Glac is an archaeological site located in Serbia near Sremska Mitrovica (Fig. 15.16) near the river of Sava. The location, as well as some details of Glac, are known since the 19th century. The archaeological remains showed a Roman connection. In April 2019 the LBI ArchPro measured an area of 4 ha with the MIRA I GPR system. For a general overview of the results interpreted from the GPR data, possible wall courses are traceable as well as highly reflective areas, which indicate quite a large building complex in the southern part of the measured area (Fig. 15.16). This Roman building complex covers an area of approximately 4,405 m² with a length of 135 m and a width of 47 m. Furthermore, through the traced walls, several building areas can be determined (Fig. 15.17).

The most western part is a possible peristyle yard. In the southwestern part of the measured area, a rectangular structure could be interpreted as a peristyle yard. The northern wall has a length of around 33 m and the eastern wall a range of about 40 m. However, as the southern wall is not visible in the data, the extensions of this possible yard are uncertain. Nevertheless, it covers an area of approximately 1170 m².

The distance between the column foundations varies between 4.2 m and 4.4 m on the western side. The column bases on the north and east are not as well visible as the ones in the west. The distance from the back wall to the columns is around 5.6 m. The column bases have a square shape and are about 0.8 × 0.8 m each.

The second part is a quite symmetrical rectangular structure covering an area of 41 × 36 m – a potential living area, or maybe a stable for cattle or horses. This complex shows smaller rooms on the west and east side, which are in general approximately 8 × 6 m large. The central part seems to be quite open, and almost no wall structures were detected, resulting in the interpretation of a large yard for this area.

Because of the lack of reflecting structures in the inner parts of the rooms, no floor can be determined, which could indicate a more common residential building part.

The third part, a rectangular structure with northeast to southwest orientation and dimensions of 29 × 19 m, can be outlined as follows. The northern half consists of three consecutive apses. Two more apses can be found within this building part as well as several small rooms, which are visible due to the flooring.

In the southern part of this area, an absorbing deposit could be detected, possibly marking younger activities in the ground than the Roman palace itself. This could be the remains of an (excavation) trench, leading to the assumption that the Roman building was disturbed at some point. Therefore, the trench must be stratigraphically younger than the Roman structures. Still, it is not possible to tell when the trench was dug or which purpose it had. Also, the structure cannot be described as linear nor regular. It has a length of around 16 m, and the deepest part is about 1.6 m wide. It appears in the data in the depth of 0.9–1.2 m, cutting through the possible floor areas of the Roman building complex.

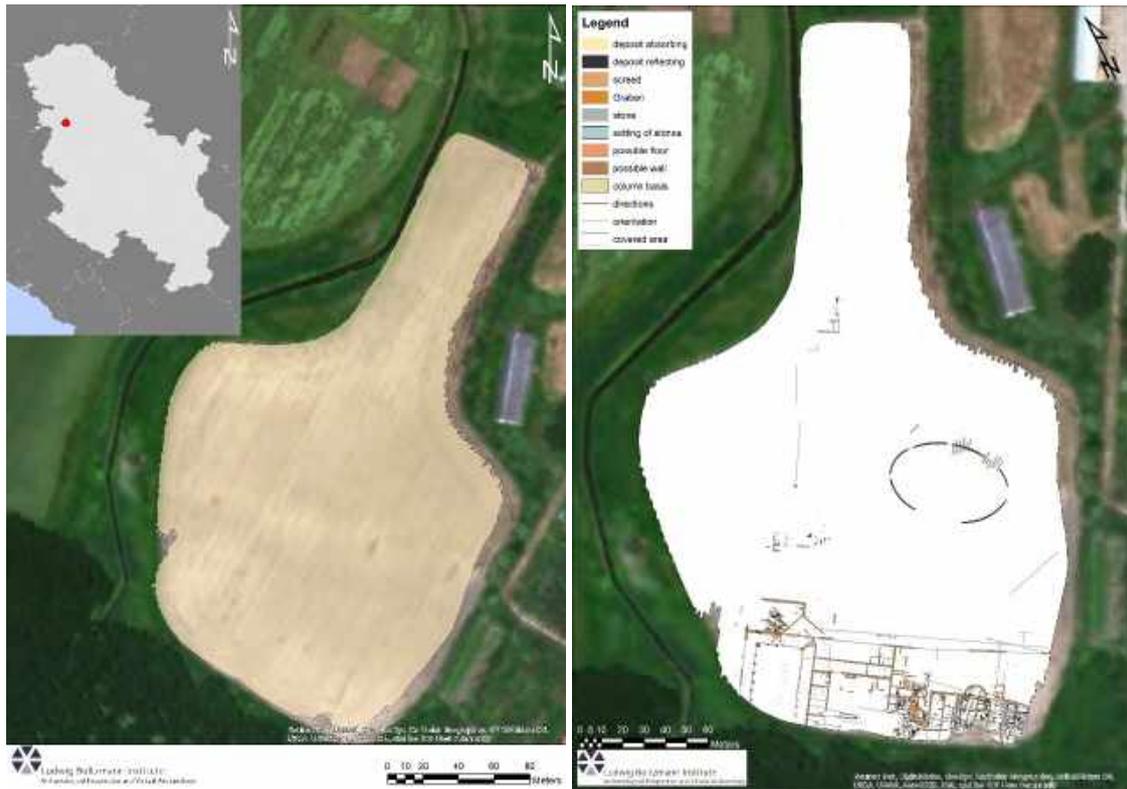


Figure 15.16: Left: Location of Glac. Right: Complete interpretation of the GPR data.



Figure 15.17: Glac: The building complex, a) peristyle yard, b) potential living or stable area, c) smaller and rectangular building structure; d) pompous part of the building complex, e) possible open area, f) portico.

15.8 Switzerland

For a few years now the Antiquities and Monuments Office of the Canton St. Gallen, the Principality of Liechtenstein and the LBI Arch Pro have been collaborating in several projects. In 2019 the LBI ArchPro did some research campaigns in the valley of the river Rhine and on the shores of Lake Zürich. Most of the carried out archaeological prospection surveys followed up on projects already started in 2017 and 2018.

Montlingen

Short description of project: Re-survey of the Bronze Age settlement on mount Montlinger under dry survey conditions

Short description of site: Grass covered hill-top, relatively even

Datasets: MIRA I

Keywords: Improved GPR data quality, high-resolution

Benefits: The resulting data is considerably better than the previous one; possibility for data set comparisons

Montlingerberg is located in the Canton of St. Gallen approximately 6 km south-east of Altstätten, close to the river Rhine. Because of the wet soil conditions during the GPR measurements in 2017 it was decided to rerun the measurements under dryer ground conditions. The repeated measurement of the plateau of the mound Montlinger Berg was conducted again using the MIRA I System. The team of the LBI ArchPro tried to figure out if the radar signal showed some more structures under dry conditions.

The areas measured in both 2017 and 2019 allow for an accurate comparison between different weather conditions of the soil. This makes it clear that more precise speed analyses should be carried out as well as a comparison of individual radargrams.

More accurate comparisons should also be made with topographically corrected data sets, and a better-resolution digital elevation model is needed. These steps should then be followed by an interpretation of highly reflective structures or probable stones, which can then be attributed to possible house floor plans.

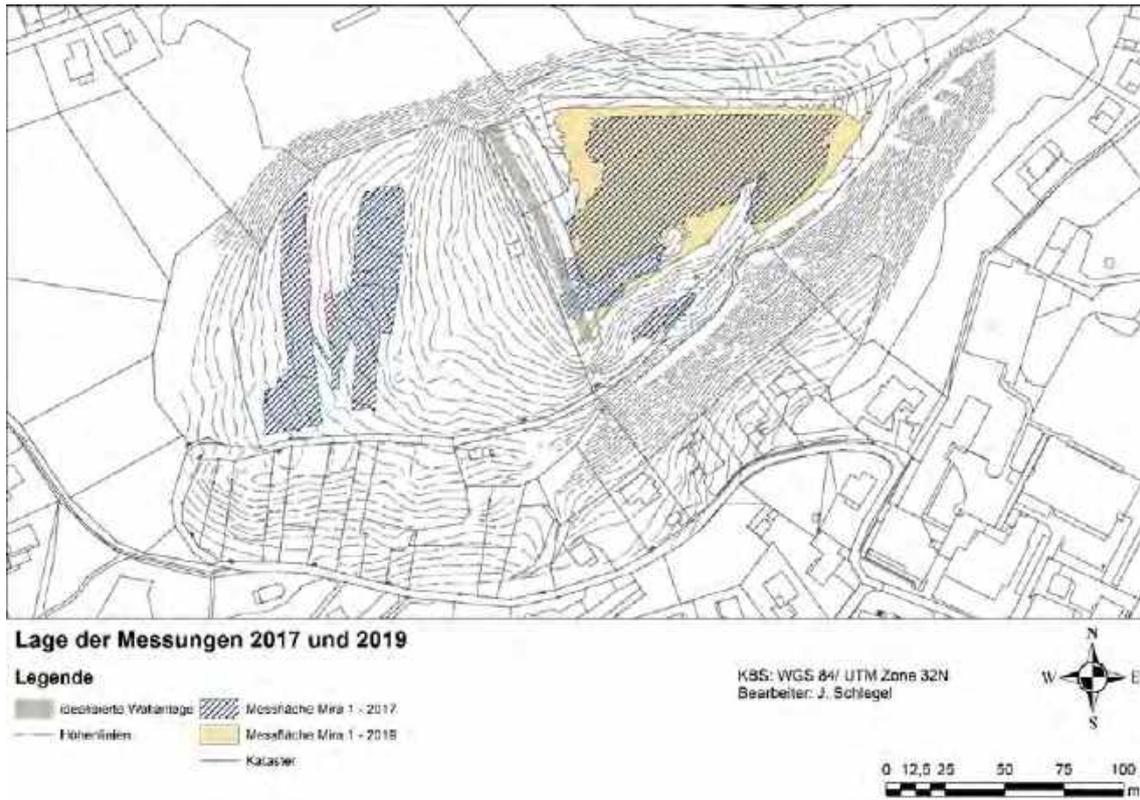


Figure 15.18: Montlingen: Measured areas 2017 (blue stripes) and 2019 (yellow) with the Mira I system.

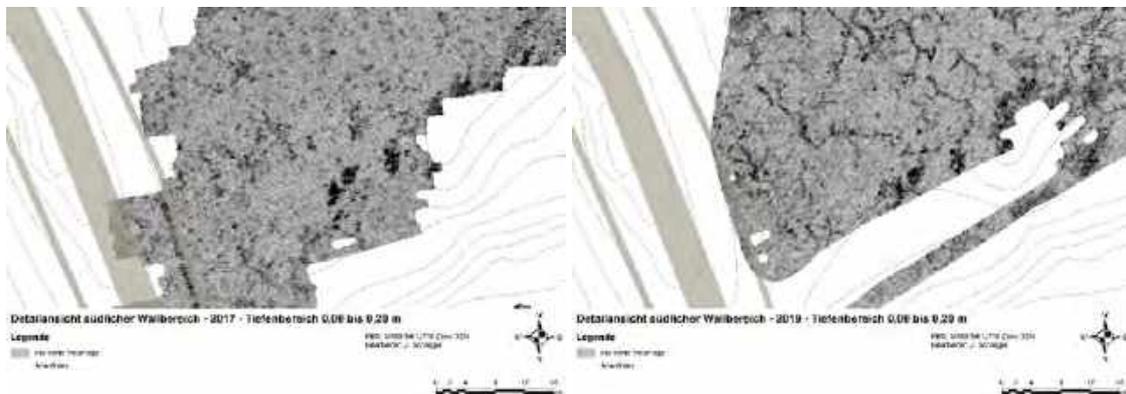


Figure 15.19: Montlingen: GPR depth-slice 0.00 to 0.20 m. Left: 2017. Right: 2019.

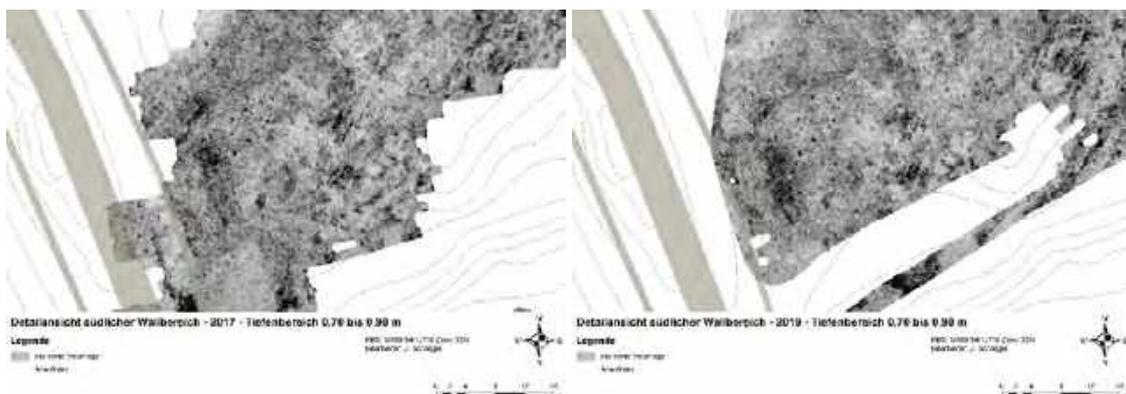


Figure 15.20: Montlingen: GPR depth-slice 0.70 to 0.90 m. Left: 2017. Right: 2019.

Alt-Altstätten

Short description of project: Third Party funded project, collaboration with Kantonsarchäologie St. Gallen

Short description of sites: 5 medieval ruins and castles in the vicinity of Altstätten, of which most have been destroyed during the Appenzeller wars. A focus is set on the ruins of Alt-Altstätten and Nieder-Altstätten

Datasets: GPR, TLS, ALS, UAV based IBM, excavation

Keywords: Interpretation of TLS data, Photo drone, combination of excavation data and TLS

Benefits: Close cooperation with future partners in the area, interpretation of subsurface and surface structures visible in TLS and ALS data, spatio-temporal analysis of the observed structures

The medieval castle of Alt-Altstätten was constructed in the year 1300 a.D. but already destroyed in 1338. Today the motte hill is still visible in the LIDAR as well as some parts of the ramparts and ditches of the defensive earthworks. Due to the fact that most of the visible remains of the castle complex is situated in an area which today is a clearing in the forest a georadar survey was conducted in October 2019. This showed some unknown building structures on the flattened area of the eastern terraces. They could probably be some workshop buildings. After these good results, a TLS scan was carried out in November to get a better topographical mapping of the site and to have a base for some possible 3D reconstructions in the future.

Within two campaigns, the castle of Neu-Altstätten and the ruins of Alt-Altstätten and Hoch-Altstätten were surveyed with TLS and GPR. A focus was set on the area around Alt-Altstätten and the close by ruin of Nieder-Altstätten only separated by 200m. For analysis, ALS and old excavation data was also included. It was possible to determine several old paths passing by the castles. A third fortified tower/ castle could be detected in the ALS data only 200 m apart. Together with huge ditch and rampart systems the whole fortification structure has been analyzed and visualized. During the documentation of the still inhabited castle of Neu-Altstätten a photo drone survey was carried out and IBM footage collected.

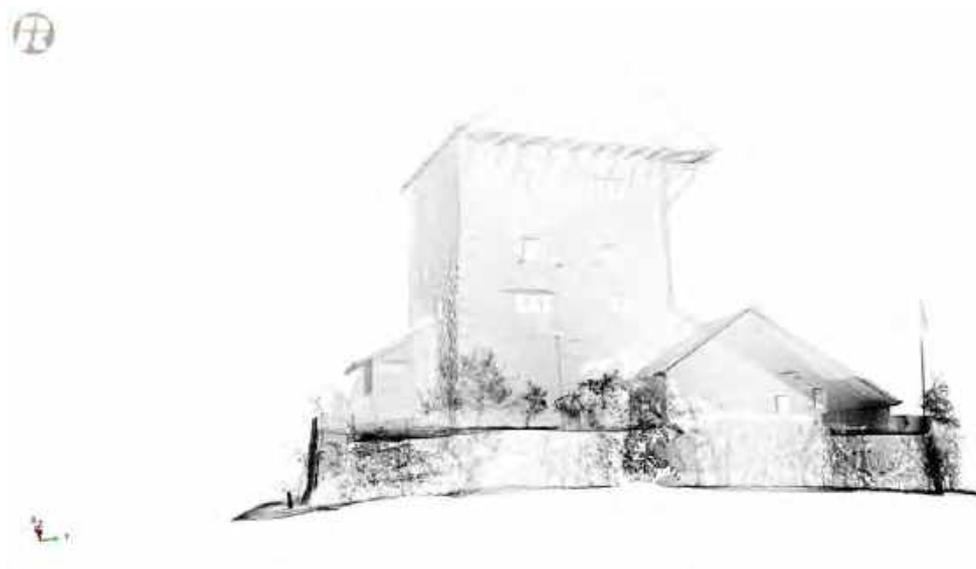


Figure 15.21: TLS pointcloud of Neu-Altstätten.

15.9 Tibet

Fieldwork Tibet Tumulus Tradition 2 project

Short description of project: Documentation of some 30 suspected burial mound sites from the Tibetan empire, FWF project support for Austrian Academy of Sciences

Short description of site: Many sites heavily damaged, in most locations no clear structures (straight walls, edges, ...) with measurable orientation.

Datasets: Photography, photogrammetric recording of sites and site survey with magnetic compass and other non-suspicious instruments

Keywords: Tibetan burial mound sites; astronomical orientation patterns

Benefits: Collaboration with Guntram Hazod, Inst. f. Social Anthropology, Austrian Academy of Sciences. Site analysis in cultural astronomy context.

In 2019, May 2nd–25th, Georg Zotti joined a fieldwork campaign for the FWF TTT2 (Tibet Tumulus Tradition 2) project led by Guntram Hazod (ÖAW ISA). The aim of the project is the documentation of burial mounds (tumuli) of the Tibetan empire (ca. 7th–9th ct.). The aim of this fieldwork campaign was to document photographically and by surveying (with tools unsuspecting to the local authorities, i.e. only photo cameras and magnet compass) discernible monument axes at around 30 sites earlier detected in aerial and satellite images in search of an assumed possible pattern of astronomical orientation. Unfortunately not many directions were visible clearly enough on the ground to allow taking meaningful measurements, and most monuments seem to follow a topographic pattern well visible in the aerial images. Many monument sites are in immediate danger of being actively destructed, or have already been considerably damaged by recent building activities in Tibet. Photographs and panorama photographs have been processed and will be published on the project website.

This fieldwork campaign also included a visit of a very interesting traditional observation site which is used again today to calibrate the Tibetan calendar. The site was documented in photos (Zotti), traditional architectural site survey (Hubert Feiglstorfer), and 3D photogrammetry (Martin Gamon). Interviews with the responsible vice director of the Institute for Astro and Medicine in Lhasa, together with copies of relevant papers (in Tibetan, translation is in progress) should provide valuable insight and material for publications planned 2021/22.



Figure 15.22: Tibet: Martin Gamon taking photographs with a camera on a pole for an image based model of a burial mound from the Tibetan empire (6th–9th ct.). Panorama: Georg Zotti.

