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Archaeological Prospection and Virtual Archaeology

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Content

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NoeL	Federal State of Lower Austria – Abt. Kultur und Wissenschaft (A)
TU Wien	Technische Universität Wien (A) – Dept. of Geodesy and Geoinformation, Institute of Visual Computing and Human-Centered Technology (A)
Univie	University of Vienna (A) - Vienna Institute for Archaeological Science (VIAS) and Institute for Prehistoric and Historical Archaeology (UHA)
ZAMG	Central Institute for Meteorology and Geodynamics – Applied Geophysics (A)
7reasons	7reasons Medien GmbH (A)
NIKU	Norsk Institut for Kulturminneforskning - The Norwegian Institute for Cultural Heritage – Digital Archaeology Department (N)
Vtfk	Vestfold and Telemark fylkeskommune (N)
LWL	Landesverband Westfalen-Lippe - Federal state archaeology of Westphalia-Lippe (D)
ArcTron	ArcTron 3D GmbH (D)

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1 Introduction

1.1 Mission

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

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

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

1.2 Interim Evaluation 2017-2020

In December 2020, the LBI ArchPro underwent a final international evaluation which was a prerequisite for the institute's prolongation and funding for its concluding 3-year runtime period April 2021-March 2024.

The evaluation involved the submission of an evaluation report and two days of online presentations and meetings with the external international evaluation panel.

The evaluation panel was composed of the following independent experts:

- Björn Brüsch: panel chair and rapporteur; Ministry for Science, Research, and Culture for Brandenburg (formerly at the evaluation unit of the Leibniz-Association);
- Valérie Gouet-Brunet: Senior researcher / Directrice de recherche (DR1) du MTES LASTIG Lab., Université Gustave Eiffel / IGN (French mapping agency);
- Tomasz Herbich: Institute of Archaeology and Ethnology Polish Academy of Sciences, Department of Applied Sciences;
- Franco Niccolucci: Director, VAST-LAB PIN - University of Florence, Scientific Coordinator ARIADNEplus – PARTHENOS, Editor-in-Chief ACM Journal of Computing and Cultural Heritage (JOCCH).

The evaluation panel delivered an exceptionally positive final report, grading the LBI ArchPro's performance with the highest mark ever achieved by a Ludwig Boltzmann institute in an evaluation.

Selected comments from the evaluation report:

"In the last few years LBI ArchPro has developed very positively and has also achieved to further sharpen its mission. Its research programme is coherent and well in line with its overarching mission. The research topics within the framework of a global processing chain – from acquisition to interpretation and visualisation of archaeological data – make the originality and high relevance of the institute and is of particular use to the international archaeological community. The triad of basic and applied research, large-scale archaeological prospection studies as well as strong efforts to disseminate its results and findings is well balanced and forms a strong competitive advantage of LBI ArchPro to competitors in its main fields of activity. "

"Overall, LBI ArchPro is an institute at the heart of European concerns about heritage preservation, which has the means to embrace a broad spectrum of theoretical and applicative fallouts, in various fields ranging from culture, education to landscape ecology, including tourism and entertainment."

"…The overall performance of the programme lines is rated "exceptional" in two cases and "outstanding" in one case."

"It is strongly recommended to continue LBI ArchPro's funding within the LBG-funding scheme until the termination of the last possible funding period in 2024."

1.3 Careers and Awards 2020

- Assistant professorship in geoarchaeology and head of VIAS was awarded to LBI ArchPro vice-director **Immo Trinks** after competitive international procedure at the University of Vienna.
- LBI ArchPro researcher **Roland Filzwieser** was awarded the Barbara Scholkmann Prize of Historical Archaeology by the University of Tübingen for his outstanding dissertation on the late medieval and early modern landscape of Scharfeneck Castle and the Scharfeneck dominion.

- LBI ArchPro researcher **Hannes Schiel** was awarded the „**Kulturpreis des Landes Niederösterreich**“ for dissemination and adult education.
- LBI ArchPro researcher **Georg Zotti** was elected a member of the **International Astronomical Union (IAU)** in June 2020.
- The joint research project of the LBI ArchPro, Odense City Museums and Langelands Museum at the Viking Age site on Ærø (DK) was chosen for **2020's Archaeological Top-10** by the Danish Cultural Heritage Agency (https://odensebysmuseer.dk/presse/nyheder/aarets-arkaeologiske-top-10/).

1.4 Research Programme

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

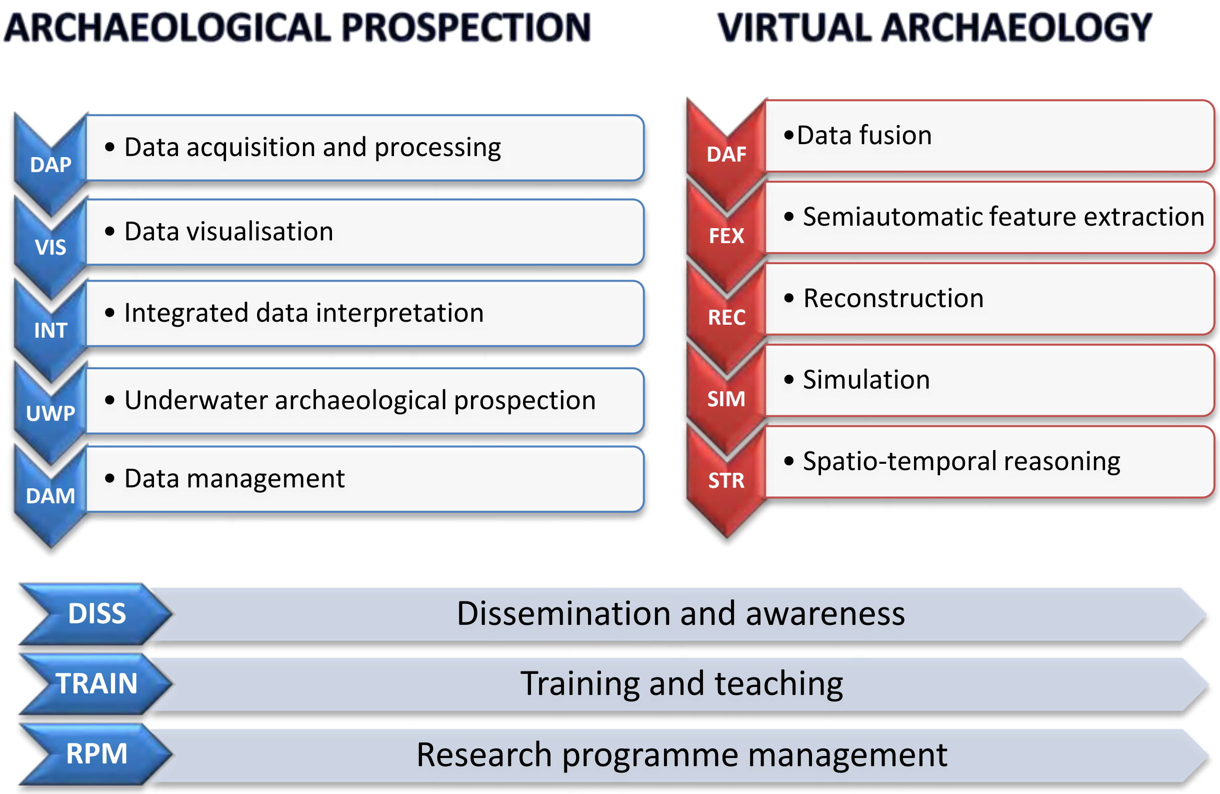

Fig. 4. Research topics within the fields ARCHAEOLOGICAL PROSPECTION and VIRTUAL ARCHAEOLOGY

The overarching subject area dissemination and awareness (DISS) warranties high profile scientific publications and regular outreach to the wider public and important non-academic stakeholders. The subject area training and teaching (TRAIN) comprises the provision of substantial academic teaching and training offered at the University of Vienna, among others, and through participation in summer schools. With the help of strategically chosen case studies the new developments are tested, advanced, and exemplarily demonstrated. Third party funded research projects offer popular possibilities for students and early-stage researchers to gather hands-on experience through participation in current, exciting archaeological prospection and digital documentation projects.

In the following, the progress made over the course of 2020 is described according to the defined research topics and lateral programme elements.

1.4.1 Impact of the Covid19-Pandemic

Due to the Covid19-pandemic and concomitant restrictions on travelling and social contacts, international fieldwork, trainings and workshops, and scientific and popular events mostly could not be carried out as planned and had to be postponed to 2021, situation permitting.

Therefore, this year’s focus was set on

- geophysical prospection surveys at national sites,
- integrated interpretation of geophysical datasets,
- research topics within the field of “Virtual Archaeology”,
- scientific publications,
- the preparation and completion of the institute’s last interim evaluation.

2 Data acquisition and processing (DAP)

2.1 Geophysics

Due to the Covid19-pandemic and related travel restrictions, geophysical prospection surveys had to be limited to areas within the Austrian borders. These investigations focused mainly on pilot studies at archaeological sites that have significant potential for future large-scale archaeological geophysical surveys and associated project applications.

Neolithic Monuments - Eggendorf am Walde, Stotzing

Short description of project: Contextualisation of Neolithic ring ditch monuments/ Kreisgrabenanlagen (KGA) by geophysics
Short description of sites: Agriculturally used fields in Lower Austria and Burgenland
Datasets: Magnetics
Keywords: Neolithic ring ditch monuments; surrounding environments
Benefits: Improved understanding of the KGAs within their environment and their relationship to neighbouring archaeological monuments

The KGA at Stotzing (Burgenland), which was newly discovered on aerial photos in 2019, was examined as part of this survey. It lies on a ridge sloping to the west and has four gates that are turned about 20 degrees to the west from the cardinal points. The entrances lie in strike and dip of the ridge. The Stotzing KGA is the first in Austria with four trenches; the outermost trench is oval. Its tip points to the topographically deepest point of the area occupied by the circular ditch next to a creek. In the next step, the immediate surroundings of the circular ditch will be investigated by high-resolution magnetometry and the ditch, which is mainly situated on quarternary gravels, by GPR.

Another focus of this survey project was on the Neolithic settlement area with an adjacent KGA in Eggendorf am Walde (Lower Austria).

Here, missing areas were measured at the KGA and most of the Neolithic settlements, however, the very wet autumn weather impeded the complete investigation. So far, the investigated area of the Neolithic settlement area is about 20 hectares with about 60 hectares being prospected in total at this site. The assumption of an incomplete outermost trench could not be confirmed. The ditch seems to have been destroyed or overprinted by agriculture and road construction. The next step will be the prospection of the area to the north towards a creek and a ridge to the south with the aim to find the associated Neolithic burial grounds.

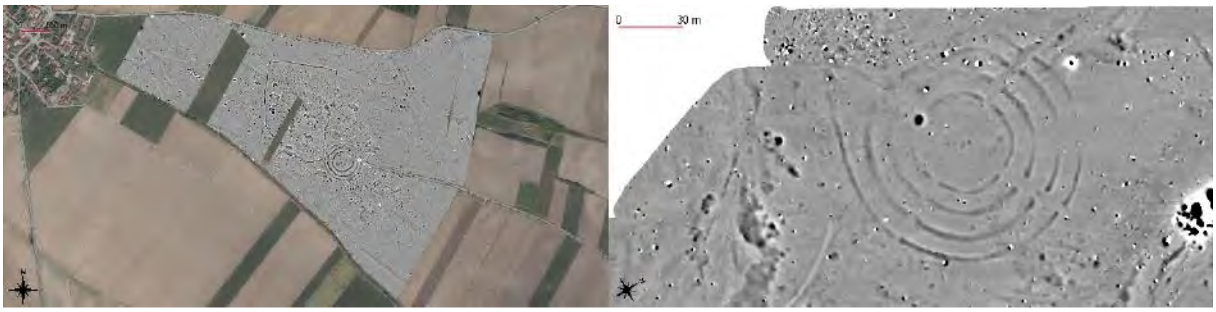

Fig. 5. Left - the extensive Neolithic settlement area in Eggendorf am Walde with an area of about 20 hectares. The diameter of the circular trench is about 120 meters. Right - the circular ditch from Stotzing with a diameter of 60 meters.

Winden am See

Short description of project: High resolution geophysical prospection of a Roman settlement area of unclear function

Short description of site: Historic mill used as open area art exhibition

Datasets: Magnetics; GPR; aerials

Keywords: Roman Kaiserzeit, settlement remains, large-scale geophysical prospection

Benefits: Expanding the knowledge for interpreting special archaeological sites; high potential for dissemination and awareness activities

Wander Bertoni (1925-2019) was an Italian born sculptor, student of Fritz Wotruba and one of the most important visual artists of the last century in Austria. He had his art studio and museum in the Gritsch mill in Winden am See. Aerial photographs have revealed the remains of a building in the subsurface of the open area, where Bertoni's works can be seen, which is to be placed in the Roman Kaiserzeit. In 2020 this was examined with GPR and magnetometry (Fig. 6). The dimensions of the structure are about 80 meters in NE-SW direction and 60 meters perpendicular to it. The walls have been preserved to a depth of 2.5 meters. The absence of hypocausts is striking. The interpretations so far range from the pars urbana of a villa rustica to a toll station and a warehouse for collecting taxes. To clarify this question, a large-scale investigation of the environment is planned. The existence of source sanctuaries and a villa rustica on the slope above is already known. The planned surveys also aim to determine the exact localisation of these structures in the coming years.

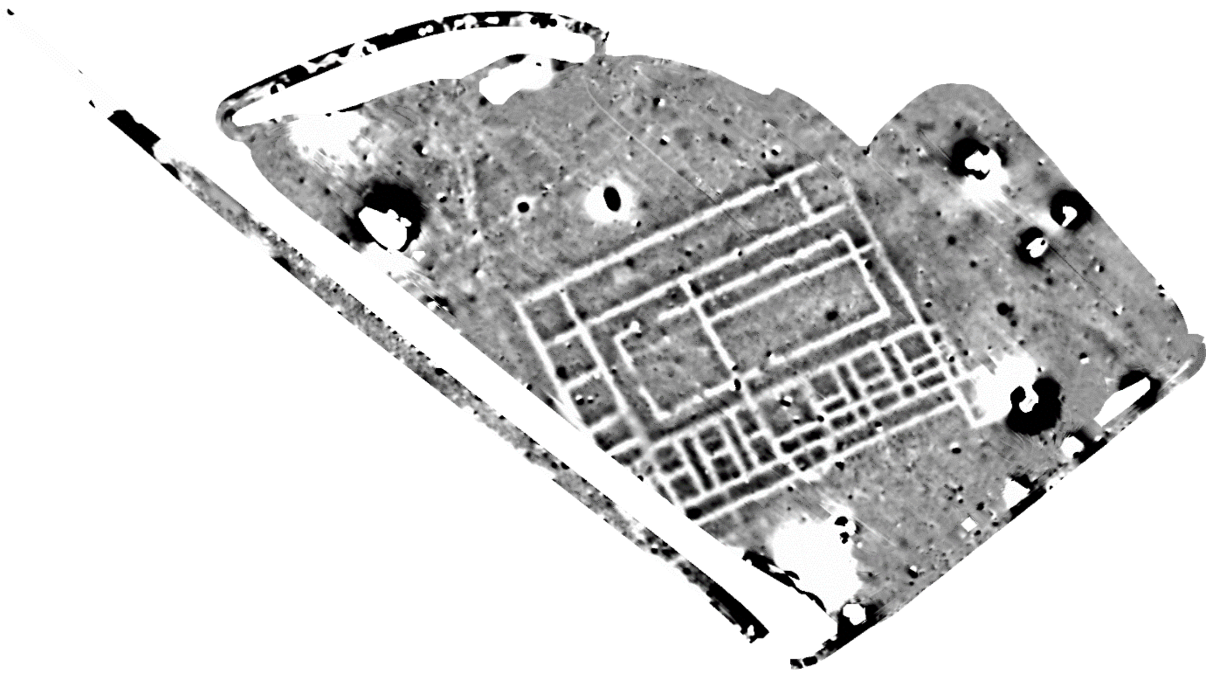

Fig. 6. Magnetogram of the building from the Roman Empire in Winden am Seen north of Arteliers Bertoni. The distinctive round anomalies are the bases of the sculptures on display.

Langes Thal

Short description of project: Detection and investigation of two deserted medieval villages and a late medieval castle
Short description of site: Two sites – Enzersdorf West and Dernberg – situated on highly eroded terrain at brooks
Datasets: Magnetics; ALS; historical sources
Keywords: Magnetometry, ALS, medieval rural landscape, castle research, deserted village
Benefits: Gaining a better understanding of the medieval rural landscape and its society; deriving a regional concept for tourism development; supporting a deeper identification of the population with their own regional history

To investigate the medieval landscape of the so-called Langes Thal, east of Hollabrunn, the LBI ArchPro has recently started cooperating with the Hollabrunn Museum Society and its head Gerhard Hasenhündl. Since the 1980s the geographer Kurt Bors has discovered countless deserted medieval villages by collecting surface finds in this area. In this project, the aim is to investigate those villages by applying geophysical prospection and remote sensing and to develop a concept to intertwine the scientific results with regional development.

In 2020, two sites were in focus. On the one hand, an unknown village west of the modern settlement Enzersdorf im Thale - "Enzersdorf West" – and, on the other hand, a late medieval motte-and-bailey castle, the so-called "Dernberg", also with an abandoned village at its foot. Both villages were situated on nearby brooks, but apart from that, little was known about the organisation and appearance.

The magnetic data yielded rather good results which allowed to detect the location and extent of both villages, although they seem to be highly eroded, showing the urgency of measures to document the sites. With the newly acquired RiCOPTER UAV, a high-resolution digital terrain model could be derived from airborne laserscanning, showing yet unknown details of the Dernberg´s microtopography and construction.

Fig. 7. Surveys at the Dernberg with magnetometry (left) as well as a the RiCOPTER UAV (right).

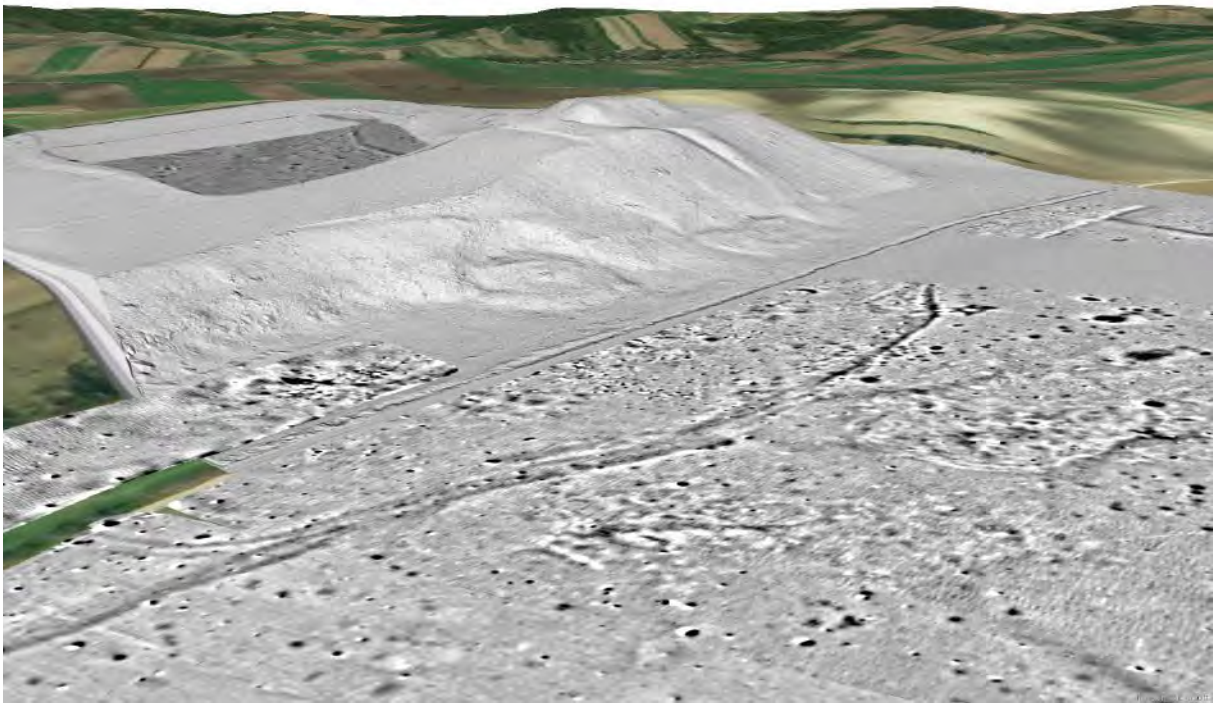

Fig. 8. Terrain model and magnetic data of the Dernberg (center) with its associated deserted village in the foreground, of which mainly the surrounding path is clearly visible.

2.2 Extension of ApSoft 2.0

The individual modules of the software package ApSoft for sophisticated data processing of geophysical prospection data, developed by the LBI ArchPro in cooperation with the partner ZAMG, were improved. The functionality of the module ApRadar was extended to handle new single antenna systems with DGPS positioning. Several filters were developed to remove external "noise" that can be observed in GPR data. ApRadar is now able to save personal defaults, to process a GeoTiff file showing the covered area in detail, to shift 3D GPR fields and to export the data in netCDF-format and to process and convert radargrams easily. The user-interfaces of the geophysical processing software ApRadar and ApMag were adapted to be used in a similar way. The software for processing magnetic prospection data, ApMag, was developed to improve the processing of manually driven systems, to reduce striping patterns, and to better handle positioning errors and ranges lacking position information. ApMag was extended to process Sensys data, to shift a Float-Geo-Tiff file and to write out statistical parameters and metadata of a Float-Geo-Tiff. The status reporting of the programs was also redesigned and extended. All software modules (ArchProGPR, ArchProMagnetic, ApRadar, ApMag) were extended to including the definition of the projection of the coordinates in EPSG format in the Geo-Tiff files.

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

2.3.1 An overview article on data acquisition parameters

In 2020, a major article on proper data acquisition for IBM has been written. It covers why one could do IBM and illustrates how to compute all the necessary acquisition parameters so that the final products are suitable for the intended goals. The paper only needs a conclusion and can then be submitted. Many illustrations and tables have been created for this paper, all illuminating concepts that have never been adequately explained in the scientific literature (e.g., Fig. 9 and Fig. 10).

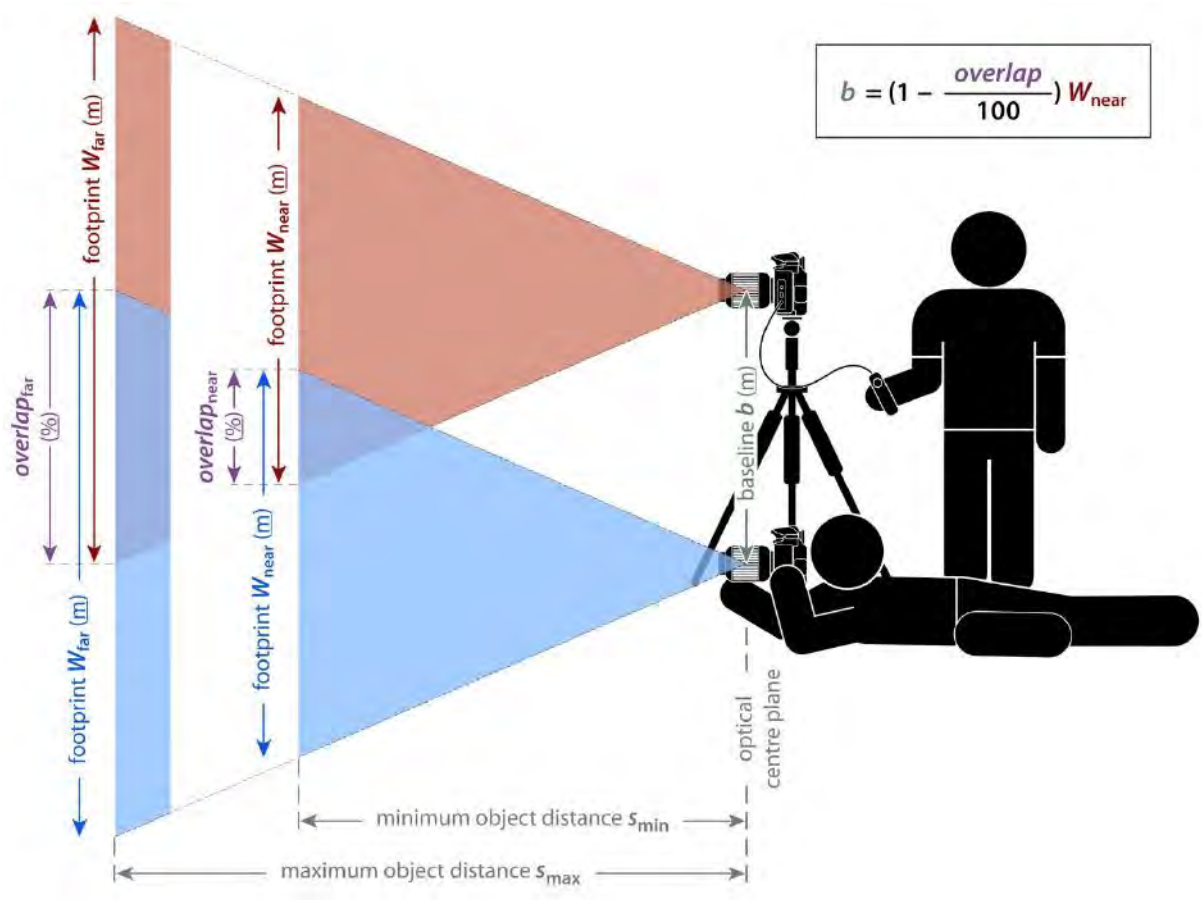

Fig. 9. Knowing the footprint and intended overlap, one can compute the maximum baseline (for both sensor's width and height). The baseline should always be computed for the smallest or not the largest relevant object distance.

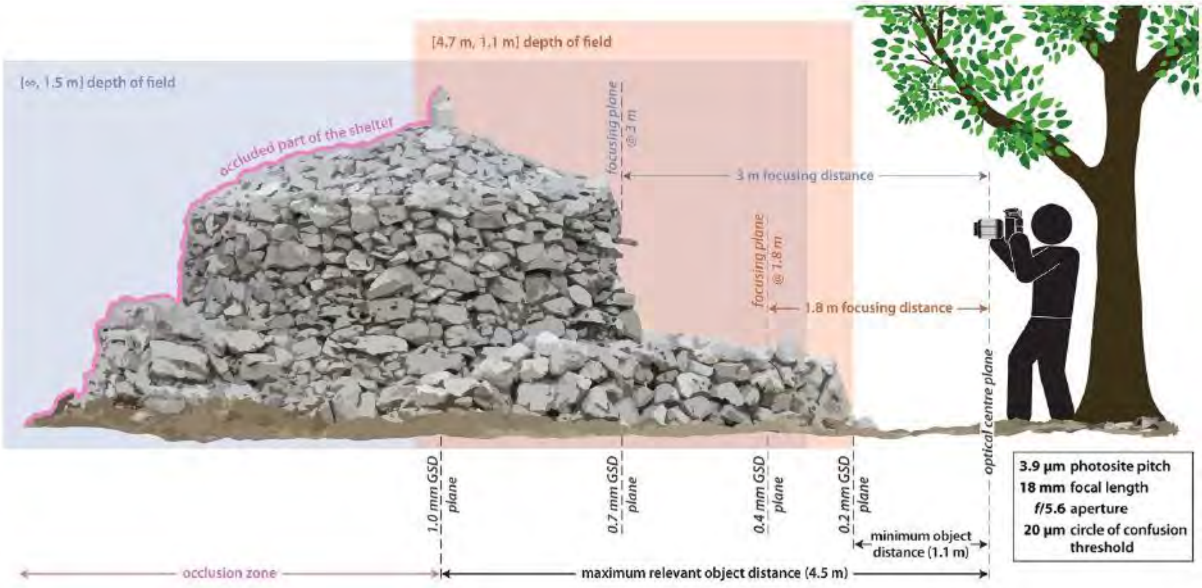

Fig. 10. Acquiring an image series for IBM of a 3D object (such as a dry-tone shelter) entails the following essential concepts: 1) due to the photographer's position, the rear part of the shelter is occluded and does not have to be covered by the Depth of Field (DoF). The maximum relevant object distance is, therefore, much smaller than the maximum object distance. 2) The focusing distance of this shelter should – in combination with the selected aperture, focal length, and Circle of Confusion (CoC) threshold – yield a DoF that encompasses all non-occluded object areas when walking around the shelter. A straightforward focusing point at 3 m would exclude the front part of the shelter and extent into non-usable parts of the object space. A focusing point at 1.8 m does, however, generate the necessary DoF range; 3) the 3D construction of object areas within the DoF is assumed to be accurate, but the different object distances generate a range of Ground Sampling Distances (GSDs). The largest of these values must be identical or smaller than the GSD necessary for the intended purpose.

2.3.2 Image-based 3D modelling of the Bischofstor fresco in Stephansdom (Vienna)

In November 2020, the question came up if it would be possible to generate a three-dimensional (3D) surface model of a supposedly Dürer-inspired/related fresco, located in the Bischofstor of Vienna's Stephansdom. From a handful of situational photographs by Immo Trinks, the fresco's dimensions and its accessibility (Fig. . 11) could be assessed. Based on this information, generating an image-based 3D surface model of the fresco seemed feasible. With Dr. Renata Burszan's help, access to the fresco was obtained on the 9th of November 2020. Although the fresco is located inside the Stephansdom's souvenir shop, tourists could not hinder the photographic activities because the shop remained closed as a precaution after the Vienna terror attack on the 2nd of November 2020.

Fig. 11. Photographing the fresco from two small scaffolding boards (photograph by Renata Burszan, adaptation by Geert Verhoeven).

The overall idea of photographing this fresco was to digitally record its surface so that geometrical details of 0.25 mm or larger would be visible. To that end, a 24-megapixel full-format Nikon D750 camera was equipped with a Tamron SP 24-70mm F/2.8 Di VC USD lens whose focal length was locked at 24 mm. The focusing ring was immobilised with cellophane tape at a focusing distance of about 43 cm (measured from the lens' optical centre). This camera-lens combination was mounted on a stereo bar, with a Godox AD200 Pro pocket flash unit to its left side. The flash unit featured the Godox H200R round flash head with a diffuser dome. A Godox X2T radio controller mounted on the D750's hot shoe wirelessly controlled and triggered the flash unit. The flash fired at 1/64th + 0.5 stops of its maximal output, resulting in a flash duration of 1/4500 s. This setup enabled a 1/200 s exposure time, which ensured that camera-induced motion blur (due to handholding the camera) could not negatively affect the photographs. Moreover, this combination of flash output and shutter speed cut out any ambient light, which meant that there was effectively only one illumination source for image acquisition. The latter is essential to accurately determine the photographs' white balance (see Fig. 12). This proper white balance notwithstanding, it must be stressed that the photographs were acquired with 3D modelling rather than colour accuracy in mind. The D750 captured 14-bit lossless compressed RAW imagery at ISO 100 and an *f*/11-aperture, the latter enabling sufficient depth of field for the focusing distance while avoiding unnecessary diffraction blur.

Fig. 12. The original photographs' orange tint and illumination gradient (A) are removed in the final images (B).

Given that two to three pixels are needed to resolve a line feature, a 250 µm geometrical resolution necessitates a GSD of circa 125 µm or smaller. With a photosite pitch of circa 6 µm for the D750's image sensor and a lens focal length of 24 mm, Fig. 13 indicates that a 0.1 mm (or 107 µm) nadir GSD is achieved with an average object distance between the camera's optical centre and the fresco of 42.9 cm (which explains the 43 cm focusing distance mentioned above).

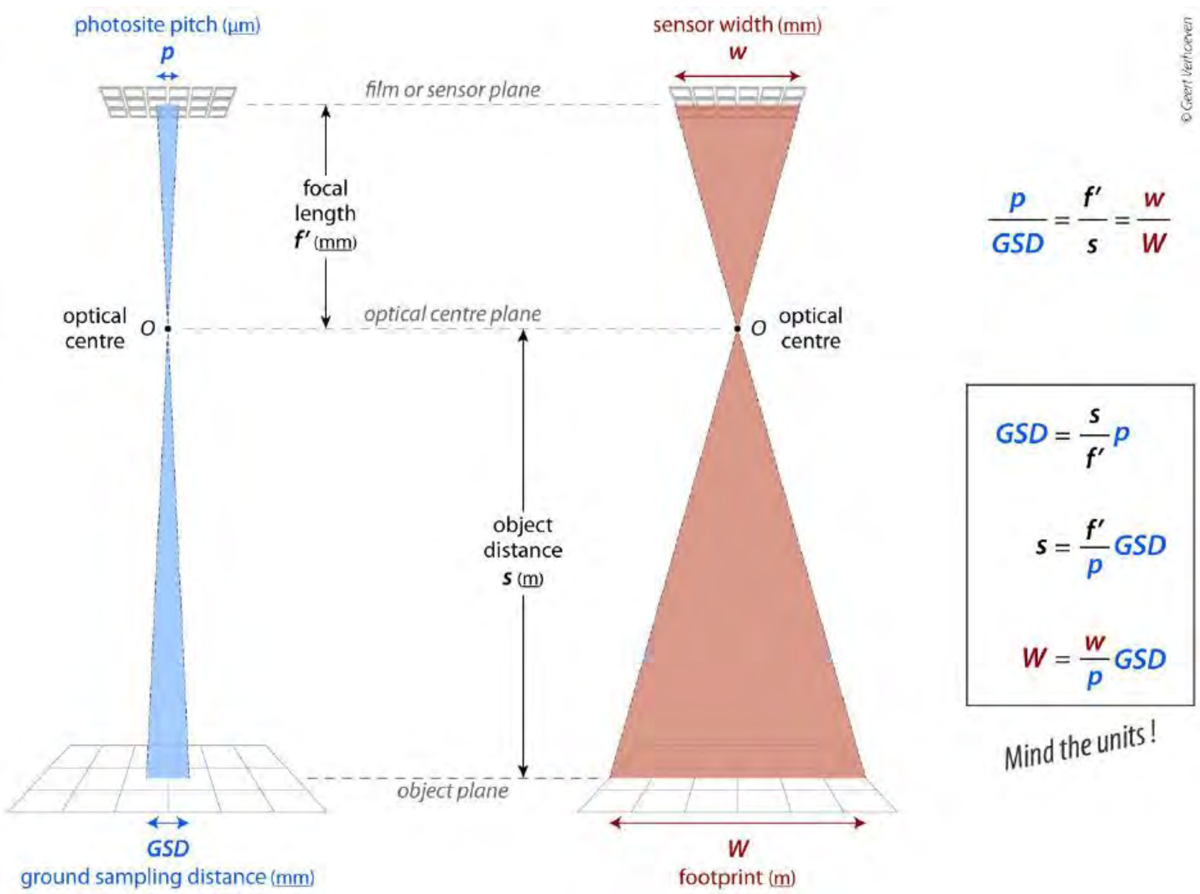

Fig. 13. Deriving the purely geometry-based equation that is fundamental to all kinds of optical imaging.

Because the image-based 3D surface extraction relies on a combination of **Structure from Motion** and **Multi-View Stereo** approaches, a high image overlap is of the utmost importance. The whole fresco was covered by 25 columns of photographs, each counting approximately 100 images (see Fig.14). The image network featured an almost 92 % **longitudinal** or **in-column overlap** and an 85 % **lateral** or **cross-**

column overlap. Note that these values represent global averages; lateral or longitudinal overlaps between neighbouring photographs are not invariant but vary a little throughout the image collection due to the hand-held image acquisition (see Fig.14). This set of 2500 nadir photographs was complemented by almost 300 images which were either convergent or for which the camera was rotated 180°, 90° clockwise, or 90° anti-clockwise around its optical axis. Some of these images also featured an increased object distance. This variation in scale and camera rotation is essential to increase the camera self-calibration accuracy during the SfM stage.

Fig. 14. The network of 2790 fresco photographs. The two horizontal gaps indicate the position of the scaffolding boards. Another column of photographs to the far left would be desirable, but the scaffolding and bordering wall prevented this.

Within Agisoft Metashape Professional 1.7.0, a 3D mesh surface was computed and given a coordinate reference system (Fig.). Afterwards, mesh errors like intersecting triangles or open edges were fixed in 3D Systems' Geomagic Design X 2019. After reimporting the error-free 3D surface back into Metashape, it was converted to a 2.5D raster surface with a cell size of 0.1 mm. This conversion of the 3D triangular mesh into a 2.5D raster surface effectively discards half a geometrical dimension. The associated information loss notwithstanding, this dimensional reduction stems from the fact that 2.5D height field rasters are still better suited for specific computational methods (like relief visualisations).

A simple but popular algorithm to visualise local topographic variations encoded in 2.5D raster files is called **hillshading**. It simulates the shadows created by an illumination source at a specific elevation and azimuth above the surface. Fig.15 depicts twelve hillshading results for the fresco surface.

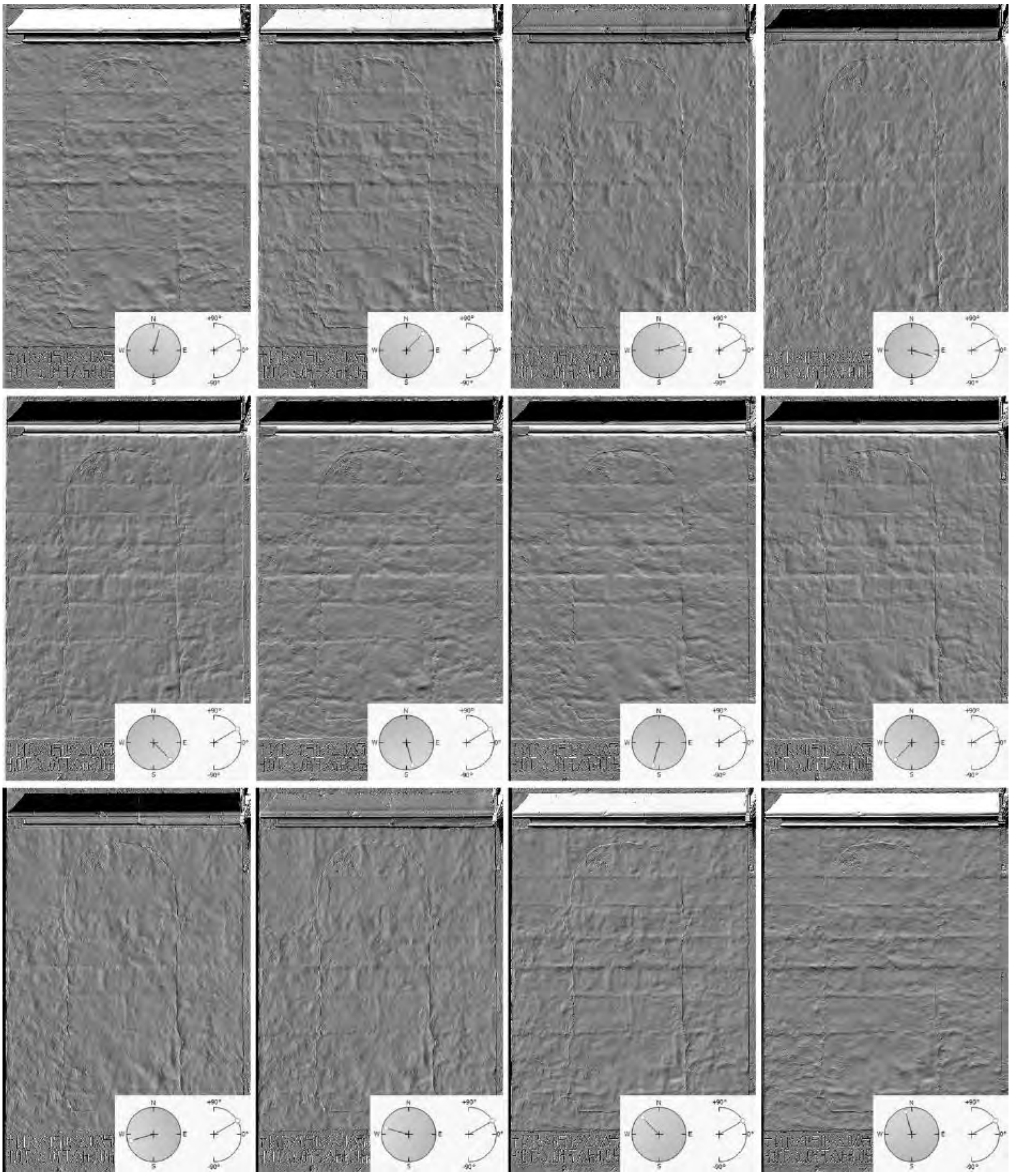

Fig. 15. Visualising the 2.5D fresco surface with the hillshading algorithm. The illumination source's elevation is kept constant at 30°, but its azimuth is changed by 30° increments (with specific values depicted by the compass insets). The contrast of all hillshade renderings was boosted to enhance visibility.

2.3.3 Education

Besides a dedicated course on photography and image-based modelling for archaeology at the University of Vienna, many theoretical and practical insights have been shared with the staff of the Landschaftsverband Westfalen-Lippe. They photographically document a vessel's excavation, while the LBI develops the RAW photographs and generates the 3D models of these images.

2.4 Terrestrial and airborne laser scanning

2.4.1 Terrestrial laser scanning

Piber – Terrestrial Laserscanning

For the digital documentation project at Piber (see chapter 14.1) the LBI ArchPro relied on equipment from collaborative partner RIEGL LMS. Besides the deployment of the newly acquired RiCOPTER UAV, the latest generation of terrestrial laser scanners, the VZ-400i series, could be used, which enabled faster data acquisition and processing (Fig.16).

Fig. 16. RIEGL VZ-400i Laserscanner in operation at Piber.

With more than 3500 scan positions, the entire grounds of the Stud including all buildings and their interiors could be digitally documented in just ten days (Fig. 17).

Fig. 17. Overview of scan positions around Piber castle in 2020.

Müllendorf - Terrestrial Laserscanning

Short description of the project: former Roman settlement
Short description of site: Roman settlement built over by modern houses
Datasets: TLS (VZ-400)
Keywords: Roman remains, excavation
Benefits: allows combination of GPR and excavation results

In addition to a geophysical survey, the excavated structures of an archaeological excavation led by the University of Vienna were documented with a terrestrial laser scanner (RIEGL VZ-400). With 17 scan positions, the areal, including the inner part of a small house, were documented (Fig. 18 and Fig. 19).

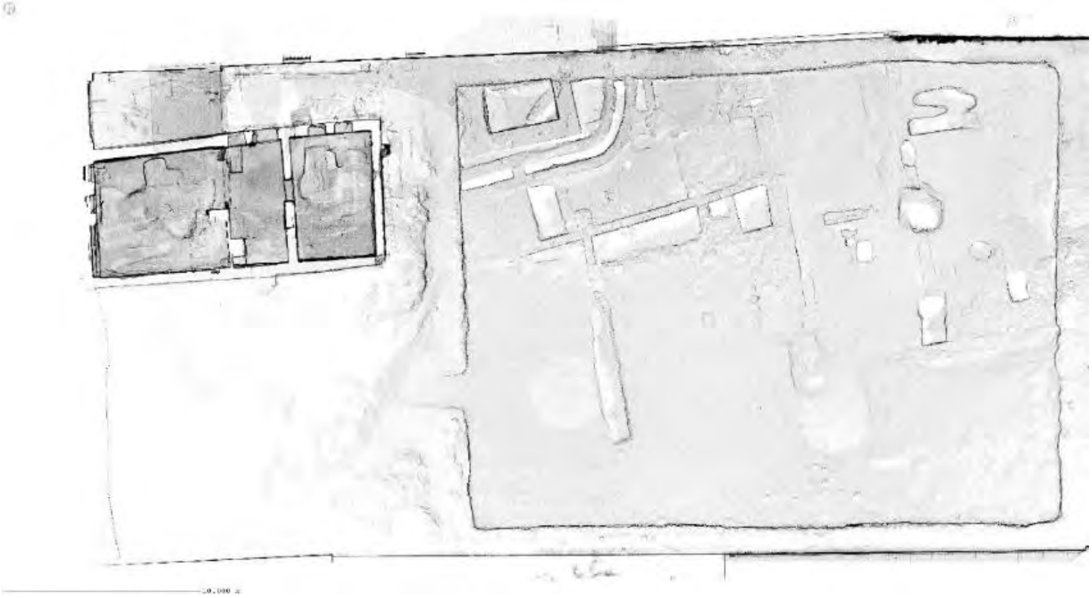

Fig. 18. X-Ray view of the terrestrial laser scanner point cloud from Müllendorf.

Fig. 19: Perspective view of the texturized point cloud, Müllendorf.

Production of Stonehenge replicas for the upcoming Stonehenge-exhibition, Herne 2021

The LBI ArchPro plans a Stonehenge exhibition in Herne to be opened in fall 2021. To generate detailed 1:1 replicas of specific stones, the LBI ArchPro has acquired 3D scans made by Historic England. This purchase notwithstanding, these scans still needed much processing to make them suitable for milling. The procured data comprise triangular meshes for every stone, but these meshes still have parts of possible surrounding elements attached (like other stones or grass – see Fig. 20). Moreover, they featured topological errors and were not available in a format suitable for 3D milling.

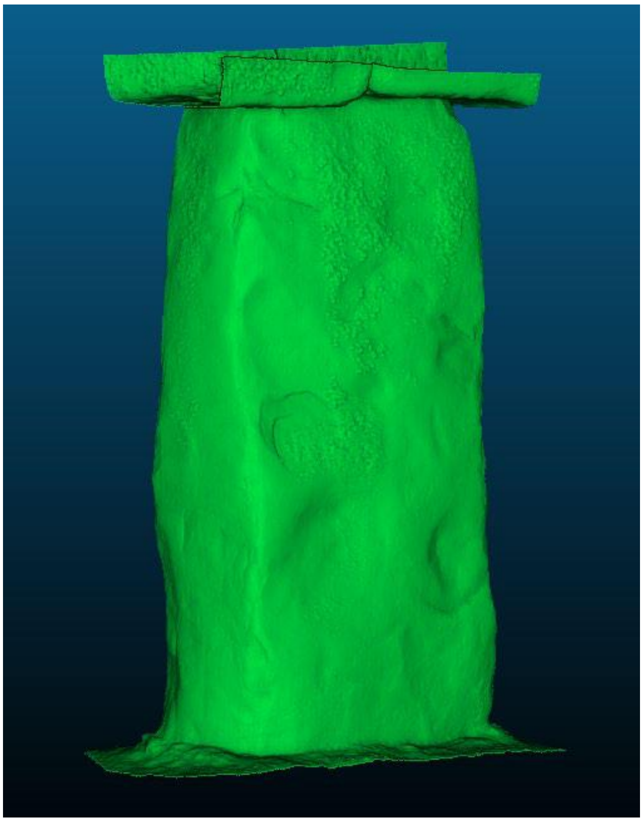

Fig. 20. Triangular mesh of one Stonehenge stone as acquired from Historic England.

In short, all stones were first made error-free. With all topological errors gone, any triangles representing attached stones or surrounding grass were removed. The created surface holes at top and bottom were closed with a curvature-aware algorithm. Finally, geometrical errors generated during the above processes were taken care of. This processing pipeline yielded watertight 3D surfaces that were geometrically error-free (in a topological sense). Figure 21 illustrates these steps, which were executed within 3D System's Geomagic Wrap 2017.

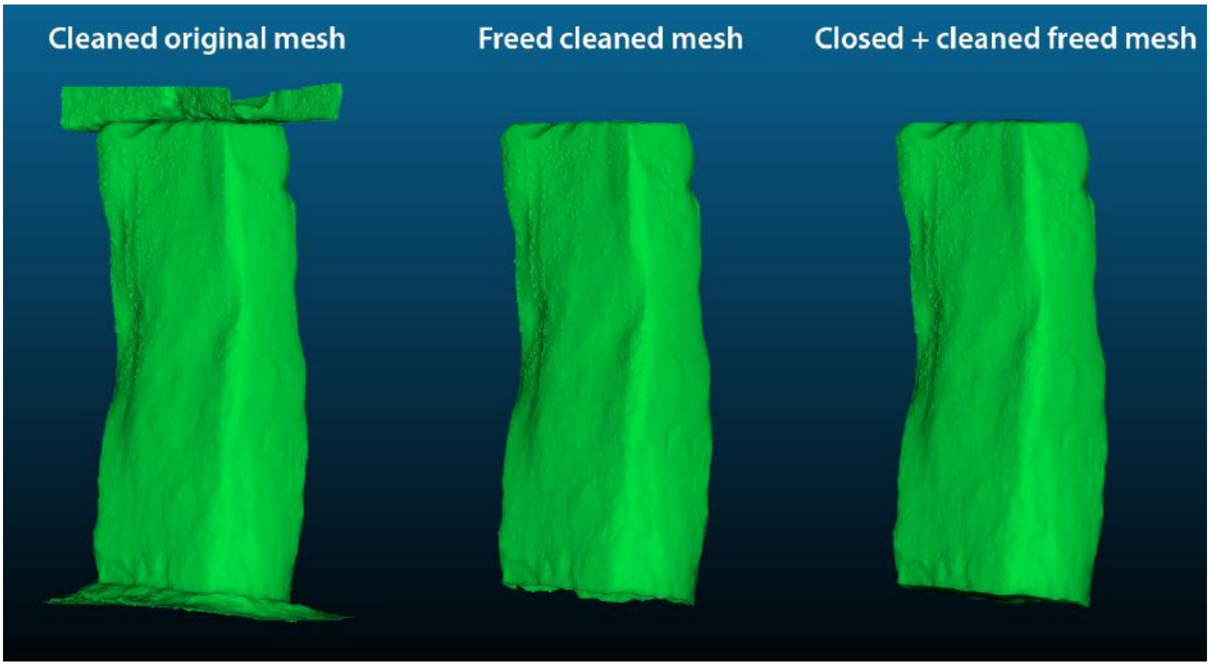

Fig. 21. All the geometry-changing steps applied to the triangular meshed stone surfaces from Historic England.

Afterwards, these meshes have to be converted to NURBS (Non-Uniform Rational Basis Spline) surfaces to make them useable for 3D milling by a CNC machine. However, this mesh-to-NURBS process is considered to be very time-consuming and usually executed with expensive specialised software. After some market research, a new, fast and accurate mesh-to-NURBS conversion software was found. This tool enables excellent autosurfacing, meaning it automatically creates very clean NURBS patches from the input mesh. Moreover, the user can steer this conversion's accuracy (with more exact conversions needing more NURBS patches – see Fig. 22).

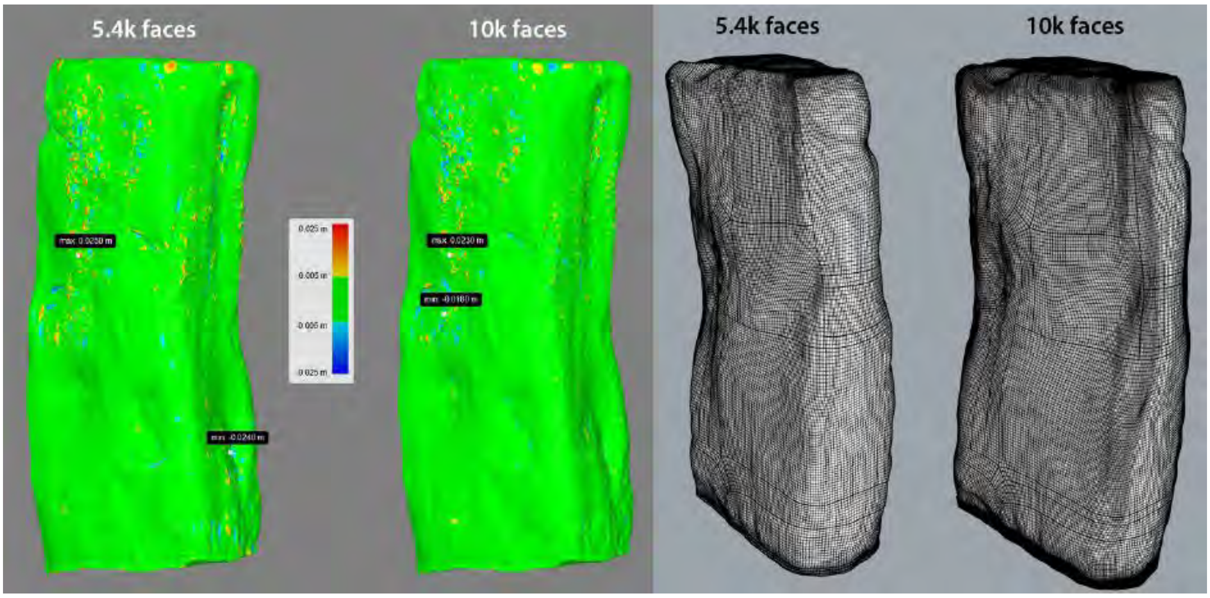

Fig. 22. Comparison of two different mesh-to-NURBS conversions of the same triangular mesh.

In this way, 24 meshed stones were converted and saved as *.iges files for milling (Fig. 23).

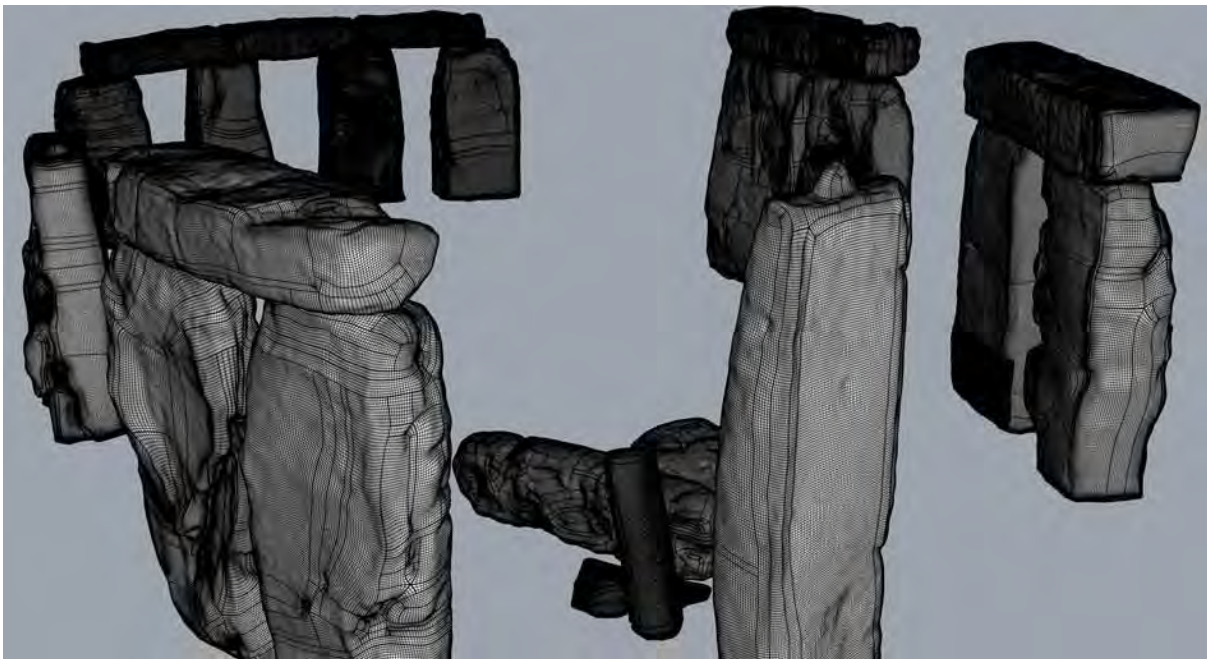

Fig. 23. The 24 resulting NURBS models.

2.4.2 Aerial Laserscanning

RiCOPTER

In 2020 an UAV operated airborne Laserscanning system from RIEGL LMS was introduced to the LBI ArchPro equipment in July 2020 (Fig. 24). It consists of a RiCOPTER C20 UAV carrying a VUX SYS Laserscanner combined with two SONY Alpha cameras for RGB data collection. The system must be operated by two persons at least, a pilot and an operator responsible for flight path planning and data acquisition. Since January 2021, the pilot must absolve a test regarding skills in operating drones to obtain a license. This license is valid within all countries of the EU.

Fig. 24. The RiCOPTER in operation at Piber.

After absolving a respective training by Riegl LMS, several training flights were carried out gaining experience. During these flights, several scenarios were trained following predefined routines. These routines including checklists and safety instructions, are highly demanding for save and secure operation of the system. A first test run was planned for the suvery at Dernberg (see chapter 2.1) and accomplished successfully in October 2020.

In November 2020, a four-week field campaign was undertaken with the RiCOPTER in Piber (Styria) in the framework of the Piber Digital project Styria (Fig. 25). The main objective regarding ALS was to cover the whole property belonging to the stud of the Lipizzaner in Piber. Within two weeks nearly 50 flights were carried out.

Fig. 25. Operating the RiCOPTER at Piber.

Besides data acquisition, the processing of the data is also challenging and must be carried out carefully, subdivided into several tasks. The data are georeferenced, aligned, classified and prepared for further archaeological interpretation or similar purposes. As a massive amount of data is collected, well-defined data management and intelligent strategies for most effective use of computing capacities is crucial. For this purpose, the network at the LBI headquarters in Langenzersdorf was redesigned and empowered, new high-end processing PCs were set up and additional storage place at the LBI´s servers implemented. As the computing time during data processing is most time-consuming, PCs can be operated remotely.

archprokml

„archprokml is a command-line tool to optimize the planning of drone missions for the Universal Ground Control Software (UgCS). The tool converts UgCS mission files to the Google Earth KML format and vice versa (Fig. 26). In this way, the user can conveniently visualize and track the mission progress in Google Earth. In the next step, the integration with ArcGIS Pro is planned. This allows the user to plan the flight route in ArcGIS Pro and export it to UgCS. Furthermore, the user can import all mission parameters from UgCS into a geodatabase.

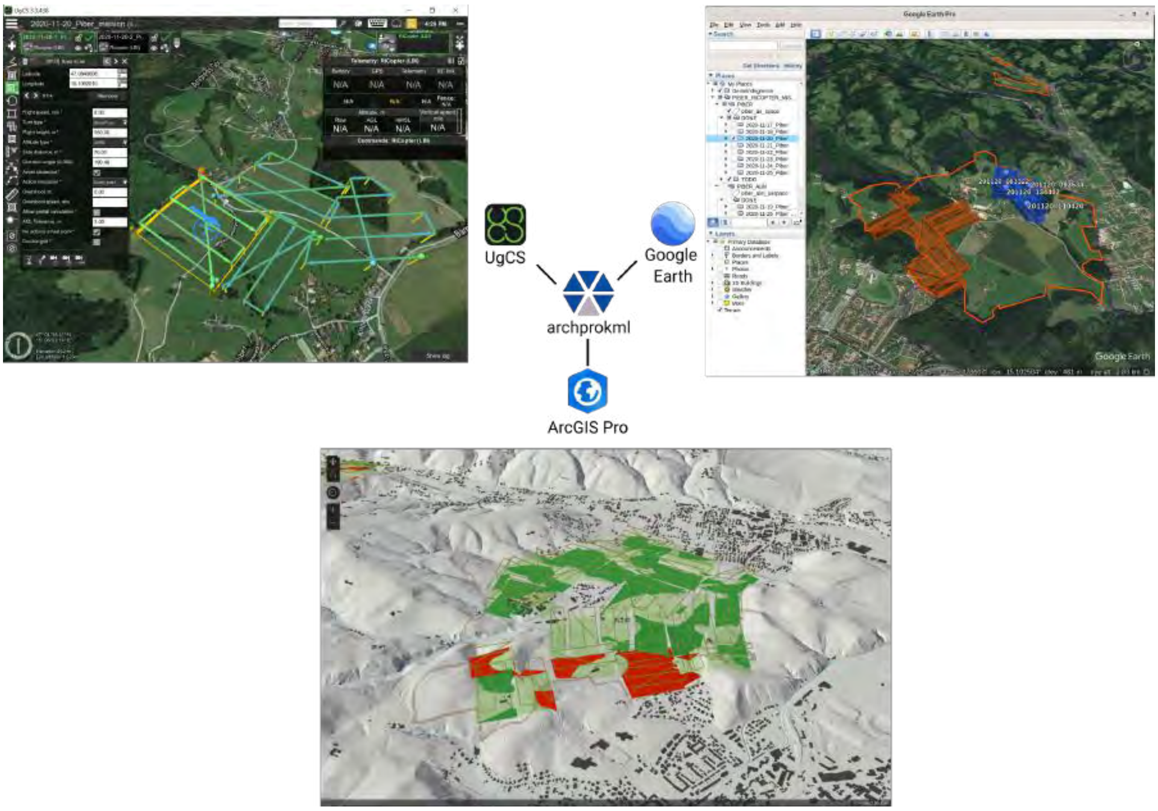

Fig. 26. The archprokml tool allows to convert KML files from one tool into another.

3 Data visualisation (VIS)

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

3.2 3D data visualisation

Revealing images generated by visualisation tailored to the nature of the datasets at hand are a key requirement for optimally exploiting archaeological prospection data. Their interpretation requires both, imagination, and a broad domain understanding. Since most archaeological structures of archaeological interest are three-dimensional, as is the way human observers understand them, it is worthwhile to investigate the possibilities of 3D visualisation with the goal to increase interpretation quality and efficiency. Therefore, former team members of the LBI CFI in Graz – Alexander Bornik and Johannes Höller - joined the LBI ArchPro and pursued their research activities towards innovative 3D visualisation techniques for heterogeneous, multi-modal archaeological prospection data, including 3D volumes (GPR), 3D point clouds (LiDAR), 3D models from image-based modelling or virtual reconstructions, and 2D images. 3D volume visualisation of GPR data generally improves the visual depiction of the archaeological 3D structures, in particular the perception of their 3D shapes, over browsing through stacks of individual 2D image in a GIS system.

The visualisation algorithm also supports the flexible conjoint visualisation of multiple GPR datasets with local control over the visualisation parameters, which allows to combine the original datasets and filtered versions from semiautomatic feature extraction.

Furthermore, manual interpretation as well as excavation 3D models can be included for comparison with prospection data. The possibilities to create 3D visualisations seamlessly integrating 3D prospection data, their manual interpretation, 3D models documenting the excavation, and complementary CAD models, lead to unparalleled possibilities for documentation, analysis and dissemination of archaeological sites and procedures in a comprehensive and easily understandable way.

Visualisation examples from 2020 include the Viking ship in Gjellestad, where a virtual ship model was reconstructed matching the GPR data evidence and visualised together with the GPR data (Fig. 27).

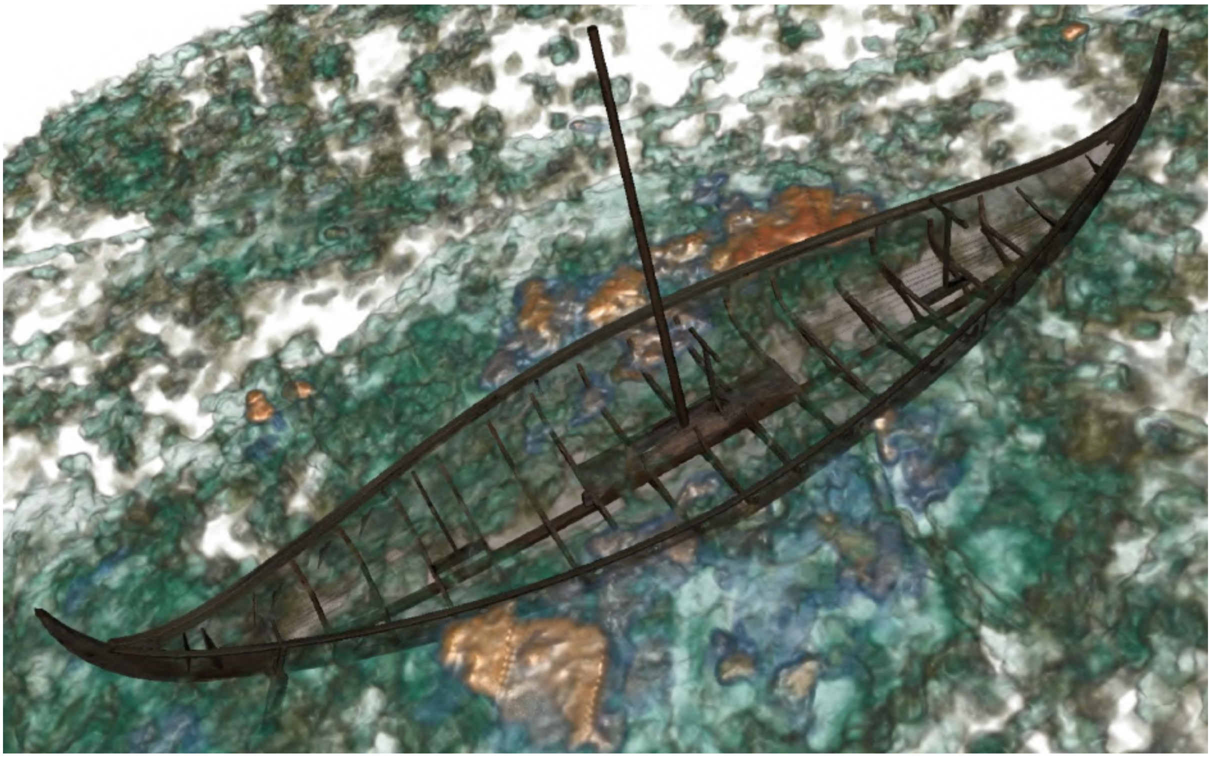

Fig. 27. Visualisation of the virtual model of the Viking ship discovered in Gjellestad in 2019 in together with the underlying GPR dataset. This type of visualisation links the virtual model to data evidence in an easily understandable way.

The existing visualisations for GPR data, interpretation, and virtual model from the Roman forum of Carnuntum were complemented with a textured 3D topography model for better assignability to the present landscape.

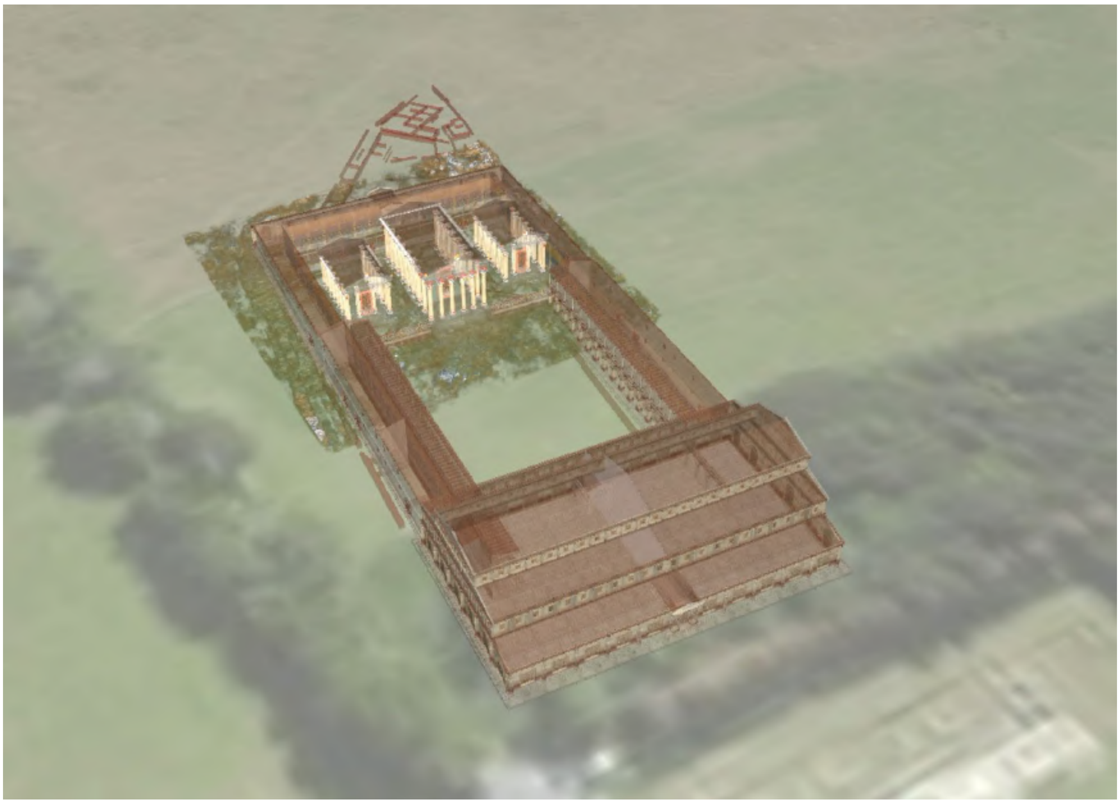

Fig. 28. Visualisation of the Roman forum of Carnuntum showing 3D prospection data, their interpretation, and virtual models in the context of the current landscape represented by a digital terrain model.

Fig. 29. GPR visualisation from the Stonehenge dataset. The new scaling feature for the GPR visualisation – in this example the depth is scaled by a factor of 2.5 - better depicts the circular ring-shaped geological structures.

3.2.1 Multi-variate data support

Archaeological prospection data is not always scalar. Postprocessing measurement images of volumes allows to extract dataset features decoupled from the underlying image grid. One practical example is the fitting of magnetic dipoles in magnetometer data images, which results in a list of dipoles with numerous properties such as location, magnitude, orientation and many others. These need to be conjointly visualized with the original measurements and other modalities like GPR.

Therefore, glyph-based visualisation techniques were adopted and integrated in the visualisation framework. Currently, they support the mapping of location, orientation, and up to four arbitrary scalar attributes to position, orientation, scale, and colour of so-called glyphs, in our implementation ellipsoids. Figure 30 shows an example of magnetic measurements in a Roman villa rustica. The conjoint visualisation of magnetics and multiple attributes of the derived dipoles in the context of GPR data enables archaeologists to deduce the presumed nature of the artifacts behind them.

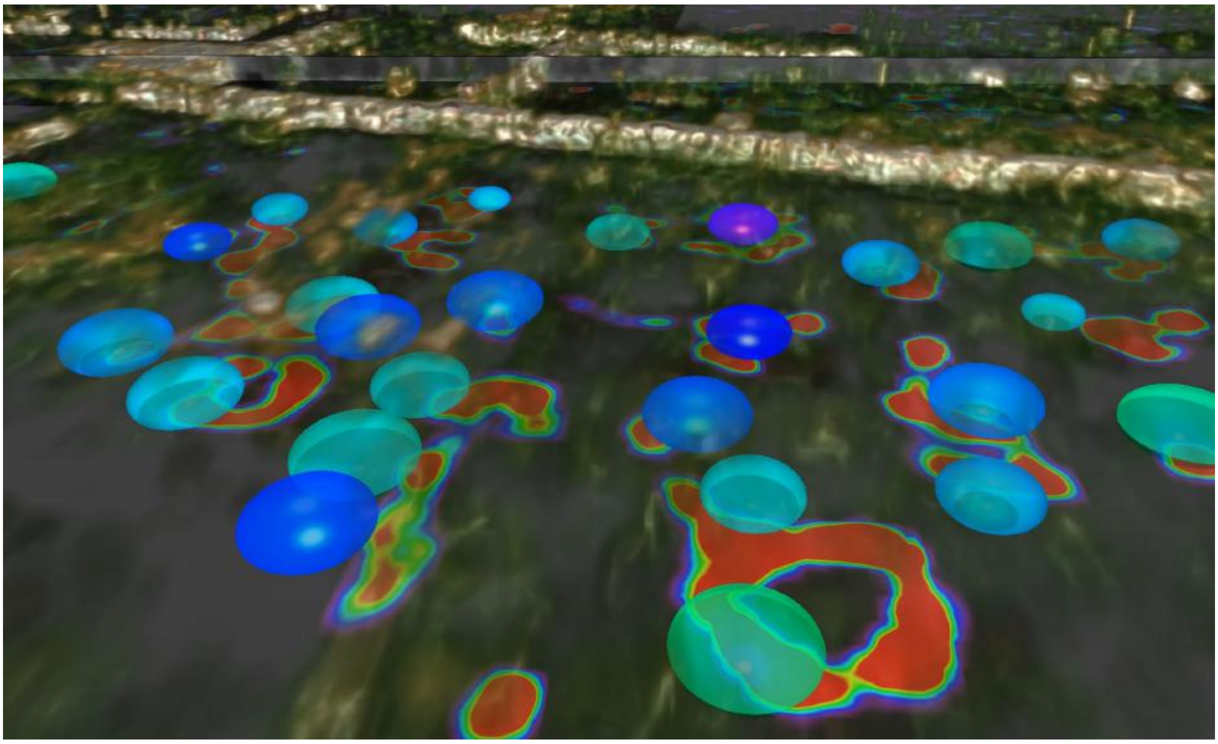

Fig. 30. Conjoint visualisation of a 3D GPR volume, a magnetometer 2D image and a magnetic dipole estimation dataset. The dipoles are represented by ellipsoids according to the 2D image position and the estimated depth, which also maps to the glyph colour. The magnitude of the dipole is reflected by the glyph size.

3.2.2 Iso-surface integration

Iso-surfaces are a well-known technique to visualize 3D volume datasets. They have been applied to GPR datasets with limited success, due to the noisy dataset nature. Combined with appropriate dataset pre-processing using filters, semi-transparent iso-surfaces are a powerful visualisation tool enabling the visual depiction of dataset-inherent interfaces as well as results from semiautomated feature extraction techniques (see also chapter 8). Therefore, the visualisation framework was complemented correspondingly. GPR volumes can now be visualised using both, direct volume rendering using a radar-value-to-colour mapping, and a radar iso-value at the same time (Fig. 31).

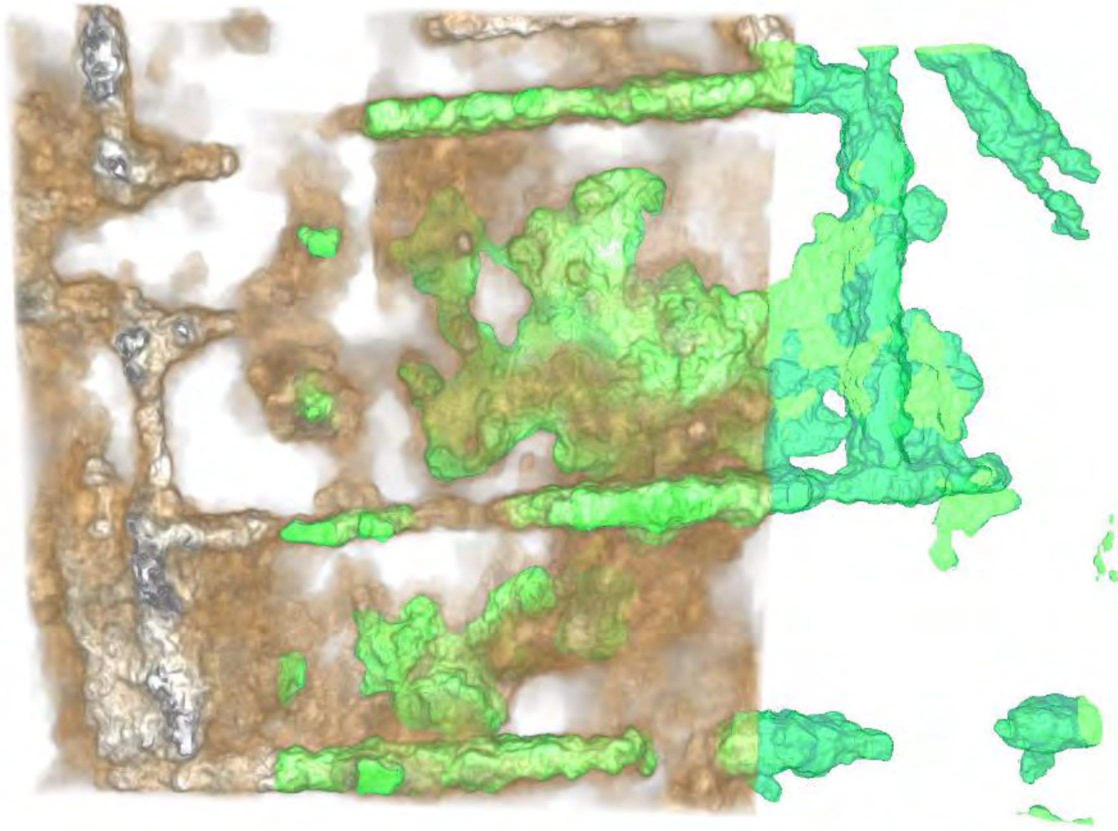

Fig. 31. Filtered GPR dataset with combined direct volume rendering and iso-surface rendering of foundation walls from the Carnuntum forum dataset. In the centre region, the green iso-surface further emphasizes the foundation wall boundary characterized by high radar reflectivity values, while other structural details remain visible.

3.2.3 Point-cloud support

Terrestrial laser scanners or our new UAV equipped with such a scanner are increasingly used to document cultural heritage in a virtual form as well as for the documentation of excavations and finds. Therefore, the support for point cloud rendering in the visualisation framework was improved leading to shorter rendering times and the possibility to render larger point clouds (Fig. 32). However, there is still room for improvement to be able to compete with dedicated point could visualisation algorithms, capable of handling billions of points.

Fig. 32. Integrated point cloud rendering. Conjoint visualisation of a GPR datasets of an Etruscan grave in Cerveteri (Italy) together with the inner surface of recorded data using a laser scanner (left). This outside view shows how well the point cloud surface matches the ceiling of the graved made of large stone blocks – red and green regions in the GPR visualisation. The image on the right shows an application combined GPR/point clouds visualisation beyond archaeology. An uncoloured laser scan of a tree complements its roots that are visualized based on GPR data.

3.2.4 Virtual Reality

In 2020 the virtual reality support of the visualisation software was improved, enabling immersive prospection data exploration using portable VR setups, e.g., a high-performance backpack PC and a head mounted display. We built a setup based on the HP Z VR backpack G2 connected to HTC Vive Pro goggles and evaluated it using various scenes. The performance of the backpack equipped with an Nvidia RTX 2080 GPU proved to be sufficient for scenes with limited complexity, therefore overlapping datasets.

3.2.5 Volume visualisation in ArcGIS Pro

Starting with version 2.26, ArcGIS Pro supports a basic form of 3D visualisation of GPR datasets based on its voxel-layer functionality. Currently, it has still limited functionality of the voxel layer in terms of flexibility – the way contributions from different datasets and representation can be combined. Nevertheless, the voxel layer will be useful for integrating volumetric datasets prepared using in-house software tools (filtering, semi-automated feature extraction, interpretation) into a full-featured GIS framework, which is clearly beyond the scope and possibilities of in-house software development (Fig. 32).

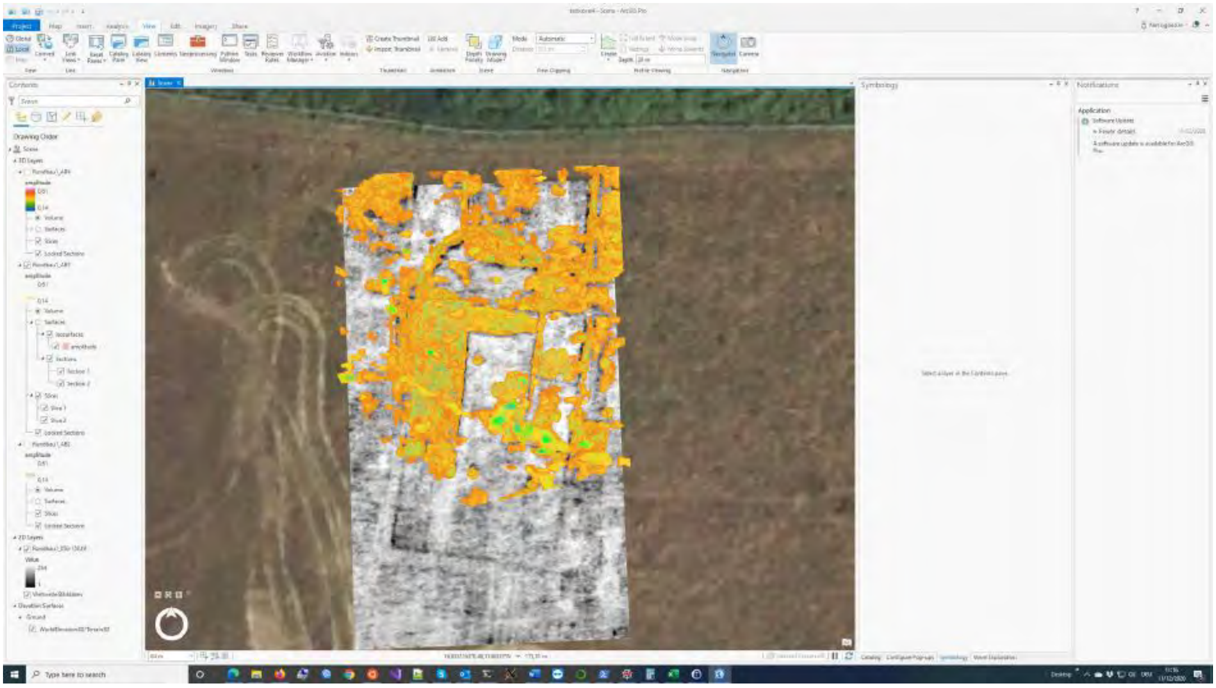

Fig. 32. Roman rotunda in Carnuntum visualized in ArcGIS Pro using the "voxel-layer". GPR data has to float above the ground DTM and GPR slice, since transparency is currently not supported.

4 Integrated data interpretation (INT)

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

However, due to the Covid19-pandemic most workshops on geophysical data interpretation with international partners such as NIKU and Vtfk had to be postponed in 2020.

4.1 Interpretation workshop to geophysical prospection projects in Denmark

Between January 20th and 24th 2020 – just before the outbreak of the Covid19-crisis - the LBI ArchPro organised an intensive interpretation workshop on the recently acquired prospection data from several important Danish sites, such as the Viking fortresses Nonnebakken, Aggersborg and Fyrkat, the famous Iron Age site Sorte Muld on the Danish island of Bornholm, and two pivotal coastal Viking Age trading places. The workshop benefited greatly from the participation of the Danish experts Jesper Hansen, Mads Runge and Finn Ole Nielsen (Fig. 33). The objective of the workshop was to gain a deeper understanding of the sites based on joint discussion of the prospection data, combining local archaeological expertise gained through many years of scientific experience on these particular sites, with the knowledge about the nature of the prospection data in a geophysical context. This process and the intense, highly enjoyable scientific discussions resulted in refined interpretation maps that provide a better conceptualisation of, and insight into these sites. The interpretation process was also supported by students and interns that were trained in the integrated interpretation of geophysical prospection data. The outcome of this workshop forms the basis for future archaeological investigations and further research approaches, with implications for both the scientific discourse as well as for the communication of the sites to the general public.

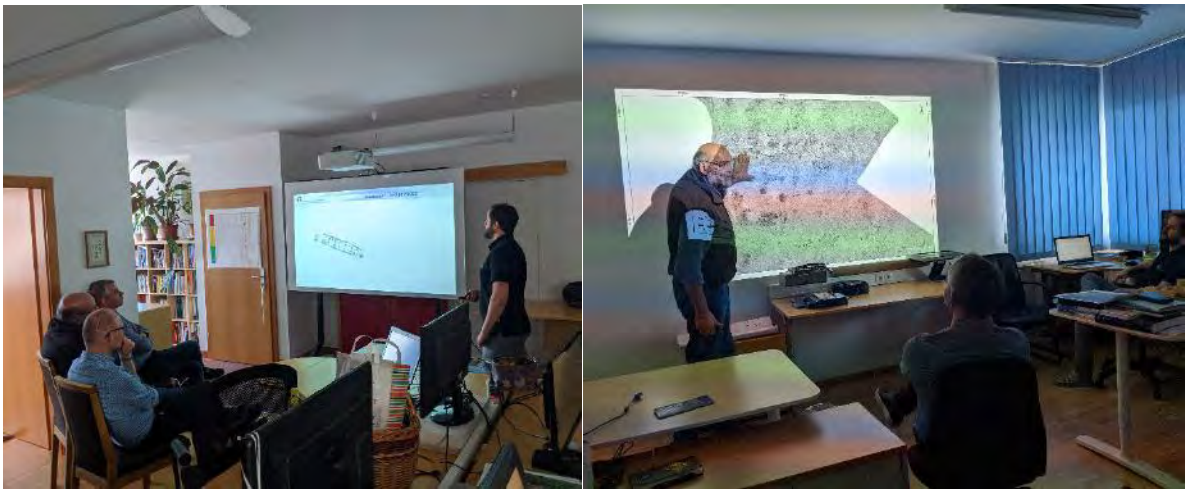

Fig. 33. Interpretation workshop with Danish experts at the LBI ArchPro premises in Langenzersdorf.

4.2 The Roman town of Carnuntum (Austria)

While the ArchPro Carnuntum project has been a research focus of the institute for several years, the ongoing data interpretation process still holds surprising results. Spatial analysis of the geophysical survey data (MAG and GPR) within the Roman civilian town has revealed the former function of another building that could be identified as a laundry (*fullonica*) by means of a cultural-historical analysis that included already excavated archaeological sites from the Roman Empire. The *fullonica* is located on one of the major roads of the city, with a convenient connection to a freshwater pipeline.

The use of water seems to have been of great importance for the ancient function of the building, since several water basins and tubs were identified within a rectangular room. In the adjoining courtyard, the laundry could be dried and ironed and then handed over to the customer in a room next to the street. This discovery represents an outstanding result for provincial Roman research, as laundries in the provinces near the Danube are so far hardly known.

Results of the ArchPro Carnuntum project will be presented in a comprehensive monography and atlas. Figures and texts have been finalized in 2020 and the publication is scheduled for 2021.

4.3 The medieval town of Corvey, Höxter (Germany)

In October 2019, a high-resolution GPR and geomagnetic survey had been carried out together with the LBI ArchPro partner LWL at the deserted medieval town of Corvey. During the first surveying campaign the entire ground-plan of the Marktkirche church could documented for the first time. The integrated interpretation of the geophysical data showed that the transeptless, three-aisled, domed basilica church, with a single-tower facade, was significantly smaller than supposed and, judging from comparable church buildings, cannot have dated from earlier than the middle of the 12th century.

The results were published in the series "Archäologie in Westfalen-Lippe" in 2020 (see chapter 12.4: Coolen et al. 2020). Geophysical surveys that had been scheduled at Westfalen for 2020 had to be postponed due to the COVID pandemic.

4.4 Montlingerberg

Short description of the project: Interpretation of the ground-penetrating radar data from 2019
Short description of site: Bronze age fortified hillfort settlement
Datasets: GPR (MIRA)
Keywords: hillfort, settlement,
Benefits: two GPR sets available

After the second data collection on the Montlingerberg in October 2019 and a first evaluation and consideration of the ground-penetrating radar data, some new contexts can be established. This includes a focus on potential stone structures, geological features, and other aspects of the surveyed area. This interpretation serves as a basis for further cultural-historical and archaeological evaluations in order to be able to tell the story of the settlement. The 3D views of the data interpretation will play a unique role here, as it will be possible to include the topography in the results. In the following, the initial findings and results of the data interpretation carried out in 2020 will be explained and highlighted.

In the 2019 data, vigorous animal activity is visible in the radar data's first centimetres. As these are both part of the data and distract the eye during the interpretation process, it was decided to interpret them. This shows that the animal passages extend over the entire area and branch out in many places (Fig. 24).

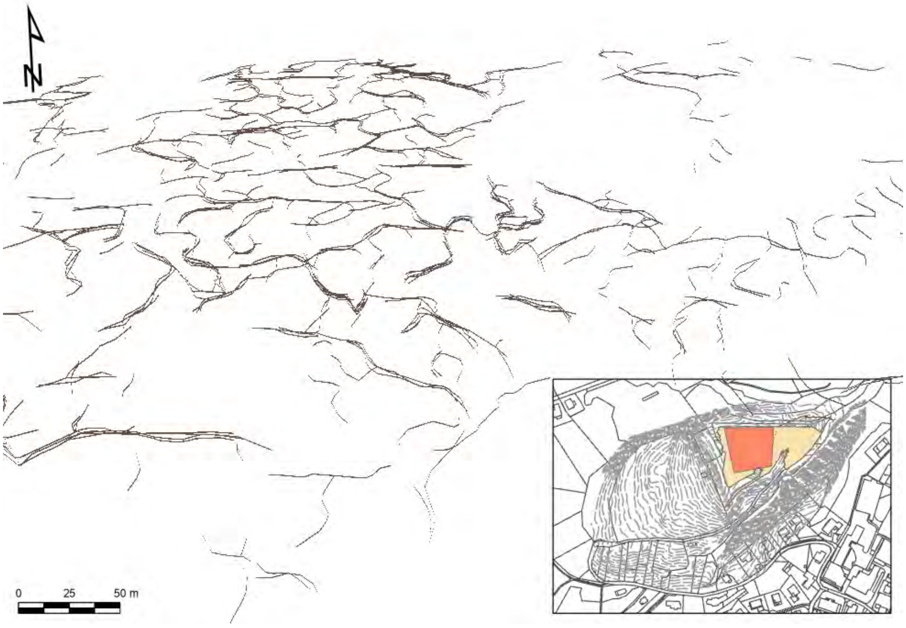

Fig. 24. Animal burrows at the Montlingerberg.

In this data interpretation, many stones could be interpreted, which cannot necessarily all be assigned to archaeological structures. The focus was on strongly reflective roundish anomalies. Depth slices with a thickness of 0.05 m were interpreted, down to a depth of 1.50 m. These were then displayed in a 3D space for the archaeological structures. These were then placed on a topographic surface in a 3D space for better visualization and examination for further analysis.

Based on these interpretations, possible house ground plans or settlement structures can be recognized and marked (Fig.). The recognized stones can be partially placed in context. The ideas and results based on the interpretations of 2017 also served as a comparison to a large extent. Furthermore, some areas can be highlighted that seem to be of particular interest.

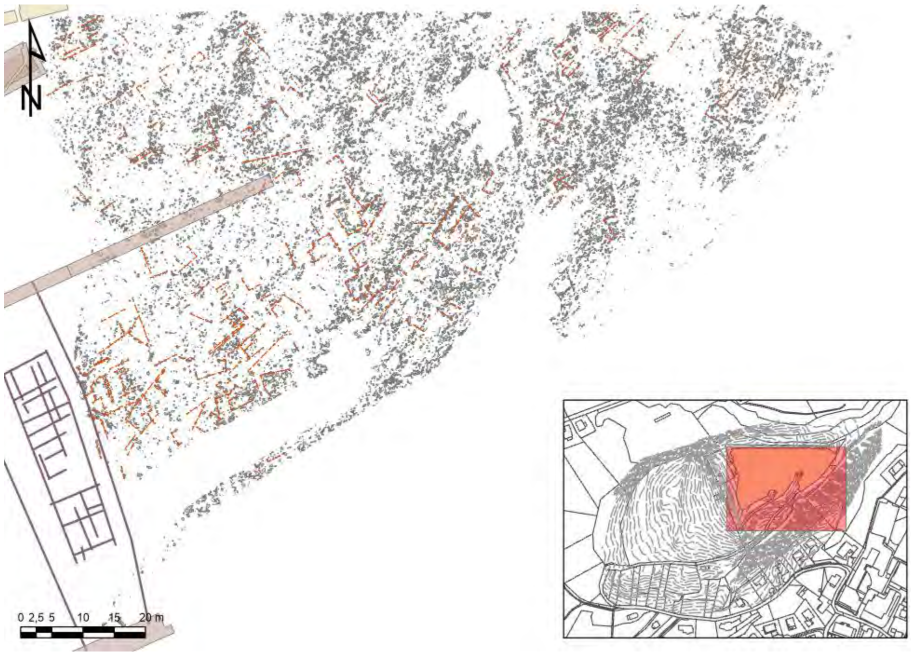

Fig. 35. Interpreted stone features (grey) and possible house structures (orange) of the ground-penetrating radar data survey in 2019.

5 Underwater Prospection (UWP)

The setup of the sonar system (IMU, RTK-GNSS, multibeam sonar) installed on the survey boat Freggel Ölf was remotely configured by MacArtney Germany. Prior to the first survey, a final calibration test in water is required. While the COVID pandemic situation prevented any sensible deployment of the survey boat in Upper Austria, progress was made with regard to the Remotely Operated Vehicle BlueROV2 acquired by partner ZAMG. This ROV is intended to be used for the inspection of targets located by multibeam sonar measurements; it has an umbilical cord of 300 m length and is designed for operation in 200 m water depth maximum. The intention is to be able to visually inspect and 3D document objects of archaeological interest on the lake bottom/sea floor with the ROV's camera by attempting underwater image-based modelling.

Several ROV pilots practiced operating the ROV underwater. The training elements involved descending and ascending, horizontal movement underwater with and without automatic depth control, steering by camera view, the use of the ROV illumination and gripper.

After initial tests in a swimming pool, on June 17th 2020 the BlueROV2 was deployed for the first time in Lake Mondsee. From the pier of Mondsee Yacht Club, the wreck of a submerged car located about 90 m to the north was inspected (Fig. 36). The car wreck had been detected at a depth of 7.5 m by multibeam echo sounder survey (Fig. 37). The target was successfully approached by the ROV and visually inspected with the ROV camera. The handling of the ROV under real conditions as well as under different flow conditions was tested. The issue of ROV navigation and orientation without visual contact or an underwater positioning system was discussed.

Fig. 36. Preparation of the BlueROV on the premises of the Mondsee Yacht Club.

Fig. 37. The rear of the car wreck filmed at a depth of 7.5 m by the BlueROV2 that is steered with an X-Box controller.

On December 16th 2020, the BlueROV2 was deployed for training in Lake Attersee in collaboration with Cyril Dworsky and Henrik Pohl of the Austrian section of the UNESCO World Heritage "Prehistoric Pile Dwellings Around the Alps" (Palafittes). First, the surroundings of the pier of Attersee were investigated with the ROV. Next, the ROV was used (Fig. 38) to successfully inspect structures on the lake bottom as well as in the pit underneath the diving platform at Strandbad Seewalchen. Underwater photographs, videos as well as overhead imagery with a drone were captured (Fig. 39).

Fig. 38. The BlueRov2 deployment at Seewalchen.

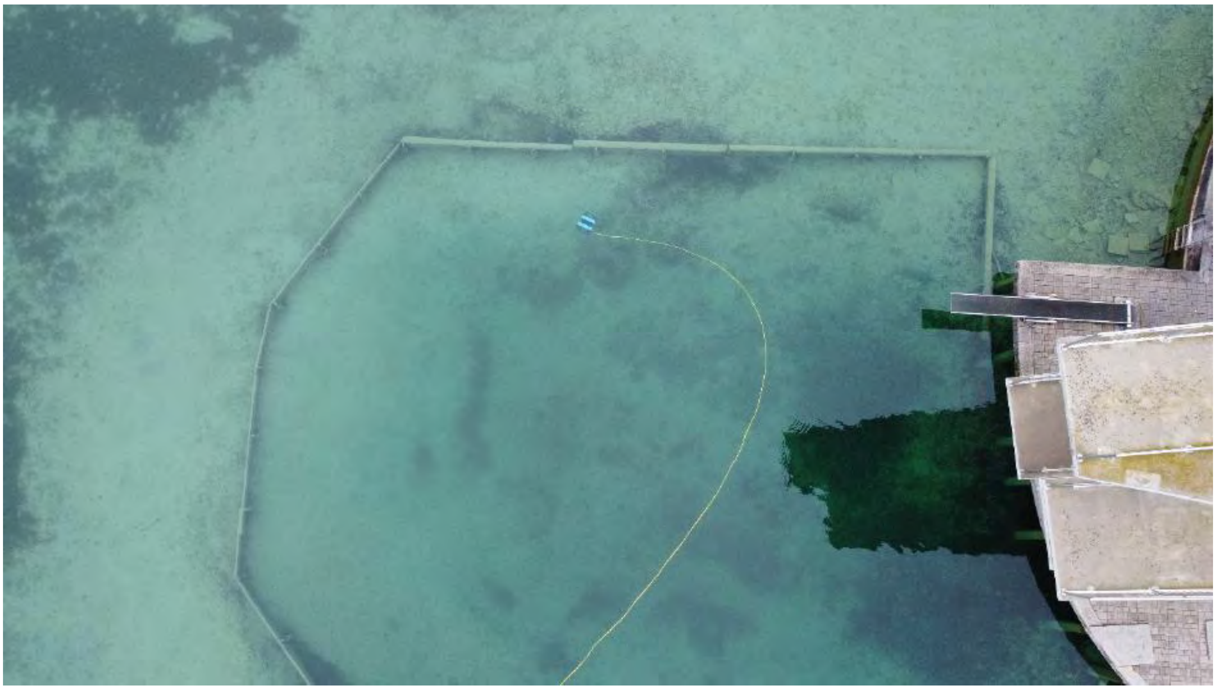

Fig. 39. Inspection of the underwater pit underneath the diving platform at Seewalchen.

On December 17th 2020, the ROV was used to explore the underwater environment of Station See at Lake Mondsee, where numerous prehistoric piles are still visible above the lake bottom (Fig. 40). Attempts will be made to extract 3D information from the recorded images and videos to test underwater image-based modelling.

Fig. 40. Inspecting the pile dwelling remains at Station See in Lake Mondsee with very good visibility.

The possibility to enhance the ROV operation and underwater navigation by an underwater positioning system, such as the "Underwater GPS"[1] with BlueROV support, was discussed and Palafittes is contemplating the acquisition of such as system.

Two small open boats that had been in the possession of LBI ArchPro partner VIAS have been mobilised, cleaned and the trailers are being brought into roadworthy condition for registration.

Multibeam sonar measurements will be continued as soon as weather and COVID situation permits. A firmware upgrade of the SeaBat Reson T-50P multibeam sensor software will permit the recording of 1024 true beams instead of the 512 beams so far.

[1] https://bluerobotics.com/store/uncategorized/aps-wl-11001/

6 Data Management (DAM)

LBI ArchPro data are safely distributed over four major locations:

- Langenzersdorf (LE), ZAMG,
- the Vienna Institute for Archaeological Science (VIAS)
- the Institute for Prehistory and Historical Archaeology (UHA) of Vienna University,
- and the centralized server room of Vienna University's IT department (ZID) at the Arsenal in Vienna.

All case study data is mirrored according to the Annex 6 (see 6.1) of the main contract with the partners at respective national servers. Annex 6 also regulates the long-term archiving of case study data on the respective national servers and/or data repositories.

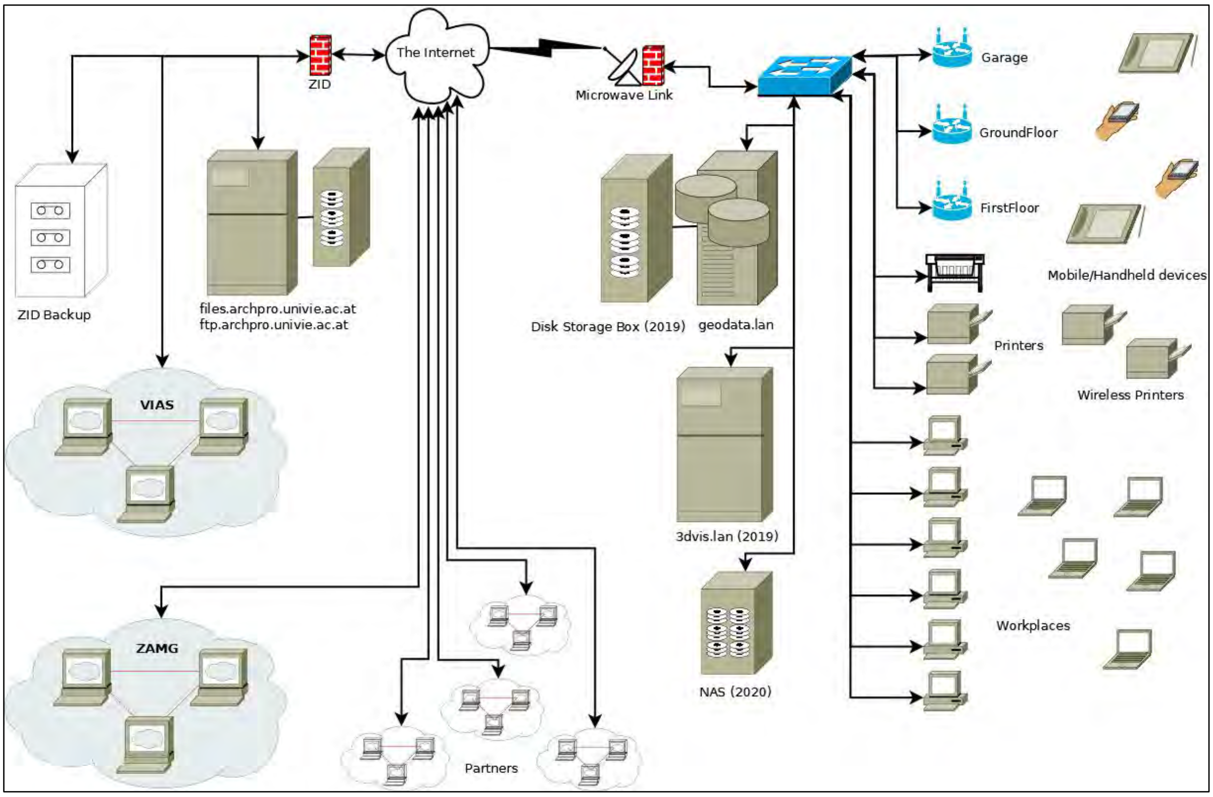

Fig. 43. Server structure.

The main file server (with 2 names, {files|ftp}.archpro.univie.ac.at) is located in the Computing Centre of Vienna University, acts mainly as data archive, and is backed up by the IT service department (ZID) of Vienna University. Its other role (under the secondary name ftp.archpro.univie.ac.at) is acting as file exchange server with the research partners.

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. Its storage capacity of ca. 28TB will be increased by another 40TB in Q1/2021 and more as required to allow hosting the backup data for the LE server.

Data archival upload from LE, ZAMG, VIAS, partners, and exchange with partners is performed via SFPT only, while for the backup solution for LE a solution with rsync can finally be installed in early 2021. 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+ and the Piber Digital project.

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 was 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 serves 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 premises in Langenzersdorf (LE) had been connected to the Internet only via 4G mobile data service until late 2020. Given this slow internet connection on the one hand and the large amounts of data on the other, a second server (named geodata.lan inside our network) has been installed in LE in 2018. This acts as centralized local network file storage for everyday work done in LE (serving Windows file shares via Samba), and shall also run geodata services (ArcGIS server, …). After a glitch in early 2020 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. Progress with the latter process was however hampered by Covid-19 measures which relegated most team members into home office. Storage capacity had to be further increased to meanwhile 70TB in Q1/2021.

In November 2020, the slow 4G mobile internet connection in LE could finally be upgraded to a high-capacity microwave link connection. This step finally opens the path to enabling archival data transfer and backup from LE to the University-hosted fileserver which is planned for Q1/2021 and allows remote access to the server data and powerful workstations in LE via VPN, which is important for data processing from Covid-19 induced home office.

Most of the data on this server so far were images processed from the raw measurement data which are archived at the Arsenal fileserver and can in principle be re-generated using ApSoft and therefore did not critically depended on another backup. However, the resulting data, geodatabases, derived images, ArcGIS projects etc., must be regularly backed up, and recent new projects are primarily stored in LE given its easier accessibility. As intermediate solution was using another NAS from LBI CFI (installed 2020) as backup storage, but as this resides in the same room as the file server in LE, this solution is less than optimal in case of elementary disasters. The intended solution to be installed now that an efficient data connection has been established will be a nightly online rsync backup to the University fileserver.

A second server had been brought to LE from the LBI for Clinical-Forensic Imaging. This acted as local backup before the NAS but shall become either a local computing resource for volumetric 3D visualisations or will be repurposed and transferred as central server for the new premises in Tieschen.

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 researchers with IT background. 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 "external" Internet.

Long-time perspectives

LBI ArchPro's data are an invaluable data resource also for decades to come, and therefore archival of raw measurement data as well as processed data (e.g., images in GeoTIFF format) and ArcGIS projects and geodata (e.g., shapefiles and equivalent data, and associated geodatabases) must be safely stored also long after the runtime of LBI ArchPro. The data in LE are stored in a flexibly expandable structure visible in figure 42.

```
.
└── SITENAME
    ├── EXCAVATION
    └── SURVEY
        ├── DISSEMINATION
        ├── GIS
        │   ├── EXPORT
        │   ├── FEATURES
        │   ├── GDB
        │   ├── HARRIS_MATRIX
        │   ├── PROJECT
        │   └── RASTER
        ├── METHODS
        │   ├── MAGNETICS
        │   │   ├── COVERAGE
        │   │   │   └── README.txt
        │   │   ├── PROCESSING
        │   │   │   └── README.txt
        │   │   ├── RAWDATA
        │   │   │   └── README.txt
        │   │   ├── README.txt
        │   │   └── SURVEY_HISTORY
        │   │       ├── PHOTO
        │   │       └── README.txt
        │   ├── README.txt
        │   └── TLS
        │       ├── CONVERT
        │       ├── EXPORT
        │       ├── PROJECT
        │       ├── REFLECTOR
        │       └── SURVEY_HISTORY
        ├── README.txt
        └── VIRTUAL_ARCHAEOLOGY
```

Fig. 44. Folder structure.

Subdirectories contain a simple README.txt containing a short description of the data. Processing steps should likewise be documented within the respective project directory.

6.1 Case study data handling (Annex 6)

Changes to the establishment contract and agreement on case study data handling

adopted by the board of the LBI ArchPro

Any changes and additions to the construction contract which are necessary are generally carried out by the board representatives in the decision-making process and are recorded in writing, usually in the form of a meeting protocol or a circular resolution. Due to the legal binding nature of such resolutions, it is not necessary to implement these amendments and additions in the form of a joint contract document to be signed anew by all the parties. This is also inappropriate due to the associated high administrative effort such a procedure would cause for the partners. The following list is therefore only intended to provide a better overview of the changes and agreements made by the Board with respect to case study data during the contractual periods 2010–2017.

(The numeration refers to the articles in the "Contract on the Establishment of Ludwig Boltzmann Institut für archäologische Prospektion und virtuelle Archäologie".)

Changes adopted by the board on 27.03.2015:

5.2.8. Press Releases have to be communicated to the contracting parties in advance.

5.3.3. Digital media (photos, videos, maps, etc.) incurred as part of the research program may be made available to the public for download by the LBG GmbH only. The LBG GmbH shall ensure that all files made available to the public contain a state-of-the-art copyright entry in the meta-data (EXIF etc.). The Contracting Parties shall, however, be free to use said digital media for publication on the Internet, provided that

(i) no better quality than required for display in a web browser is used;

(ii) any pictorial representation has a copyright caption in accordance with section 5.3.1;

(iii) the meta-data of the published files, in particular the copyright entry, are not changed.

With regard to the "Contract on the Establishment of Ludwig Boltzmann Institute for Archaeological Prospection and Virtual Archaeology" and the respective board decisions in the contractual period 2010–2014 the following shall be clarified, respectively agreed:

1. All national case study data collected by the LBI ArchPro is archived at the central LBI ArchPro repository at Vienna and mirrored at the national partner's data repositories.

2. All additional data relevant for the case study collected or hosted by the national partner is made available for the interpretation process.

3. The national partner will be provided with all information necessary for legally required reporting to national cultural heritage boards of national curators by the LBI ArchPro.

4. No national case study data shall be made available to third parties by the LBI ArchPro or by the national partner without mutual agreement.

5. After completion of the scientific work and initial publication the LBI ArchPro will make the case study data available for archival deposition in respect to national legislation or best practice.

6. Any scientific publication of the national case study data needs the agreement of the national partner and the LBI ArchPro.

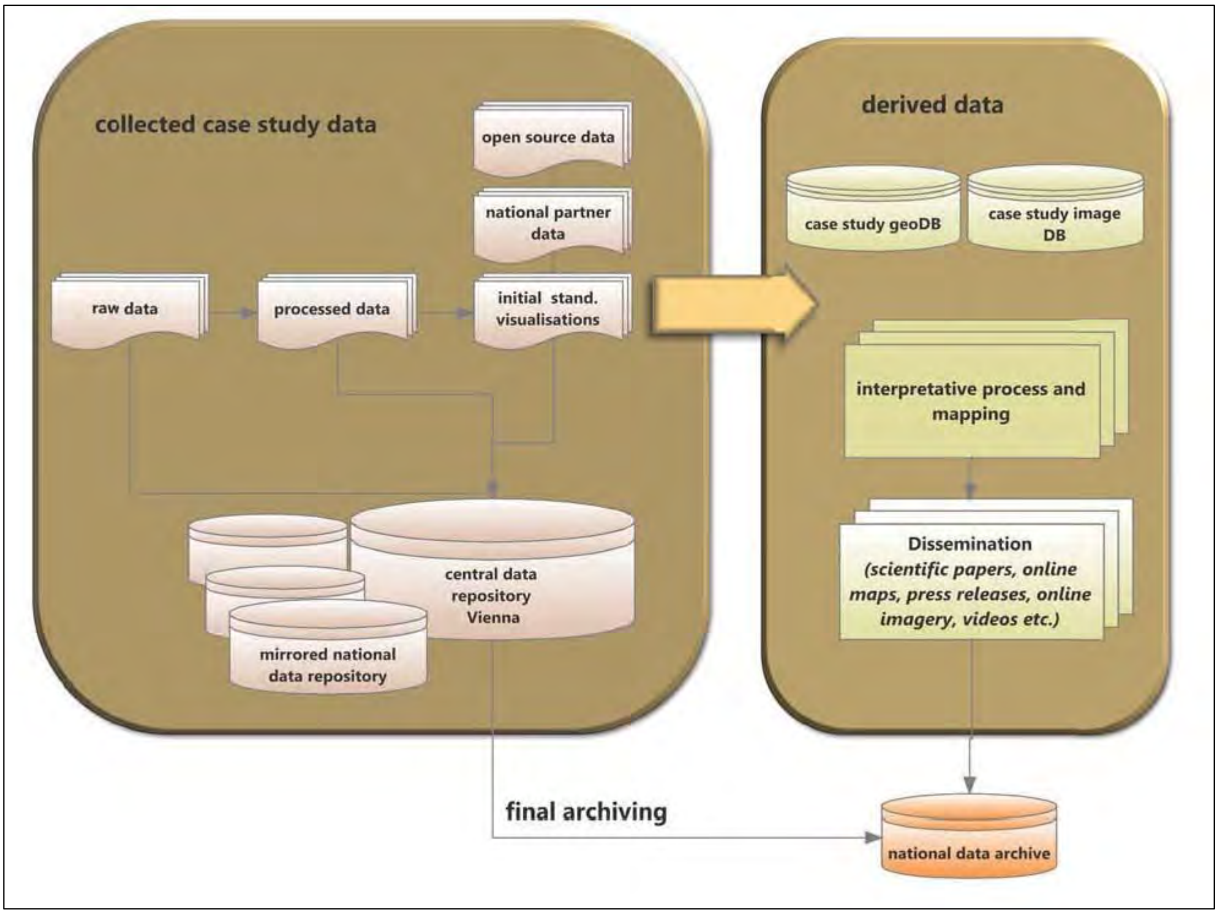

Fig. 45. Data archiving.

7 Data fusion (DF)

7.1 TAIFU

Over the past four years, much new functionality and many fusion methods have been added to TAIFU (shorthand for the LBI ArchPro's Toolbox for Archaeological Image Fusion). In 2020, TAIFU was extended with:

- an expanded wavelet-based fusion method;
- a new "convolutional sparsity-based morphological component analysis fusion" (Fig. 44);
- enhanced batching capabilities;
- sigmoid tone mapping for *.flt files;
- detection of corrupt GeoTIFFs;

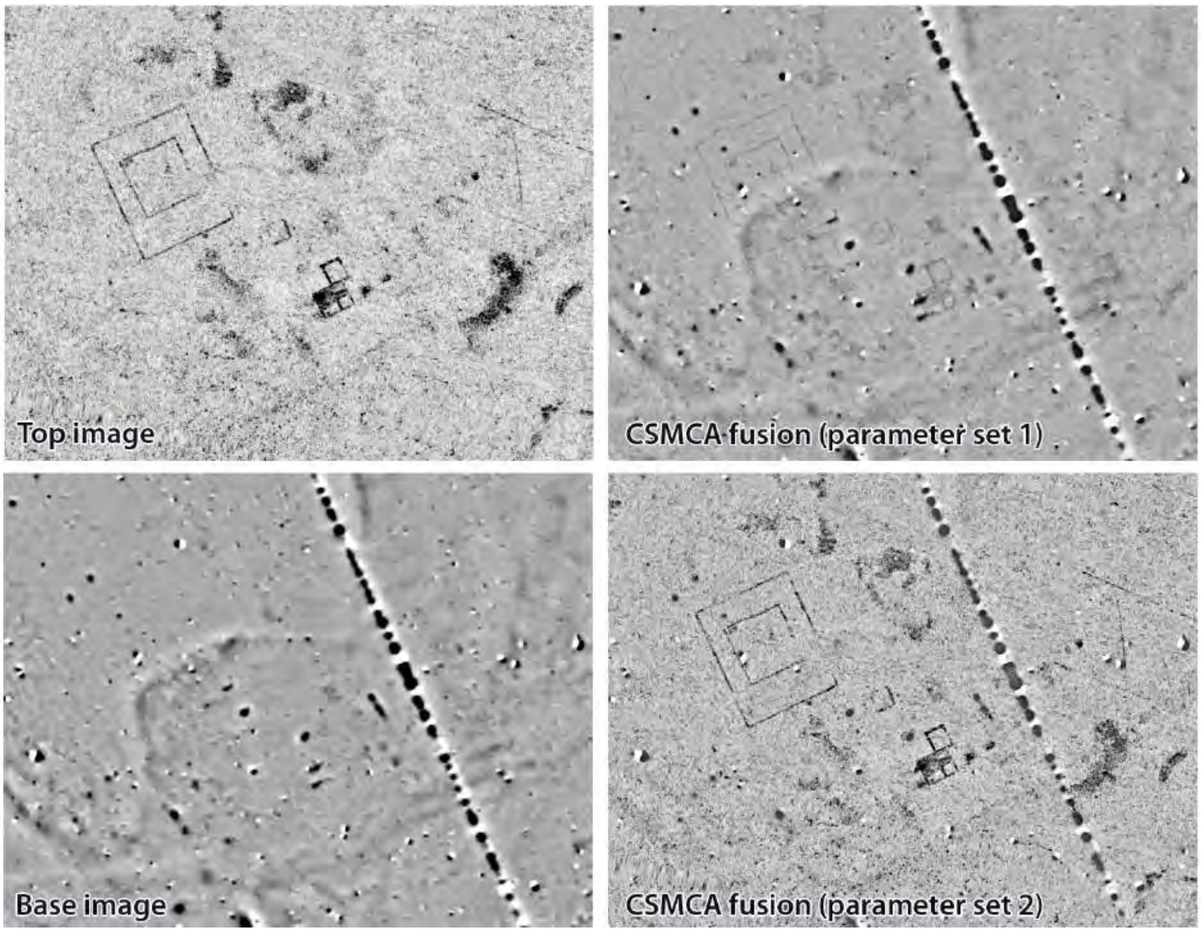

Fig. 44. The top and base image of the Walchen test dataset (on the left) and two fused outputs using the Convolutional Sparsity-based Morphological Component Analysis (CSMCA) image fusion method (on the right).

At the end of 2019, all embedded fusion algorithms were applied to five different test datasets to understand these algorithms' effectiveness for specific input data.

8 Semiautomatic feature extraction (FEX)

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

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

8.1 Denoising Filters

Therefore, filters suppressing small structures and noise while emphasizing larger structures, ideally those of archaeological interest like foundation walls, ditches or postholes are in demand. Based on first experiments with edge-preserving smoothing filters in 2019 we investigated the applicability of alternative approaches including median, bilateral, anisotropic diffusion filters and the variational approach deliberately chosen in 2019 (Fig. 45) for pre-processing GPR data for 3D visualization. All filters have their pros and cons.

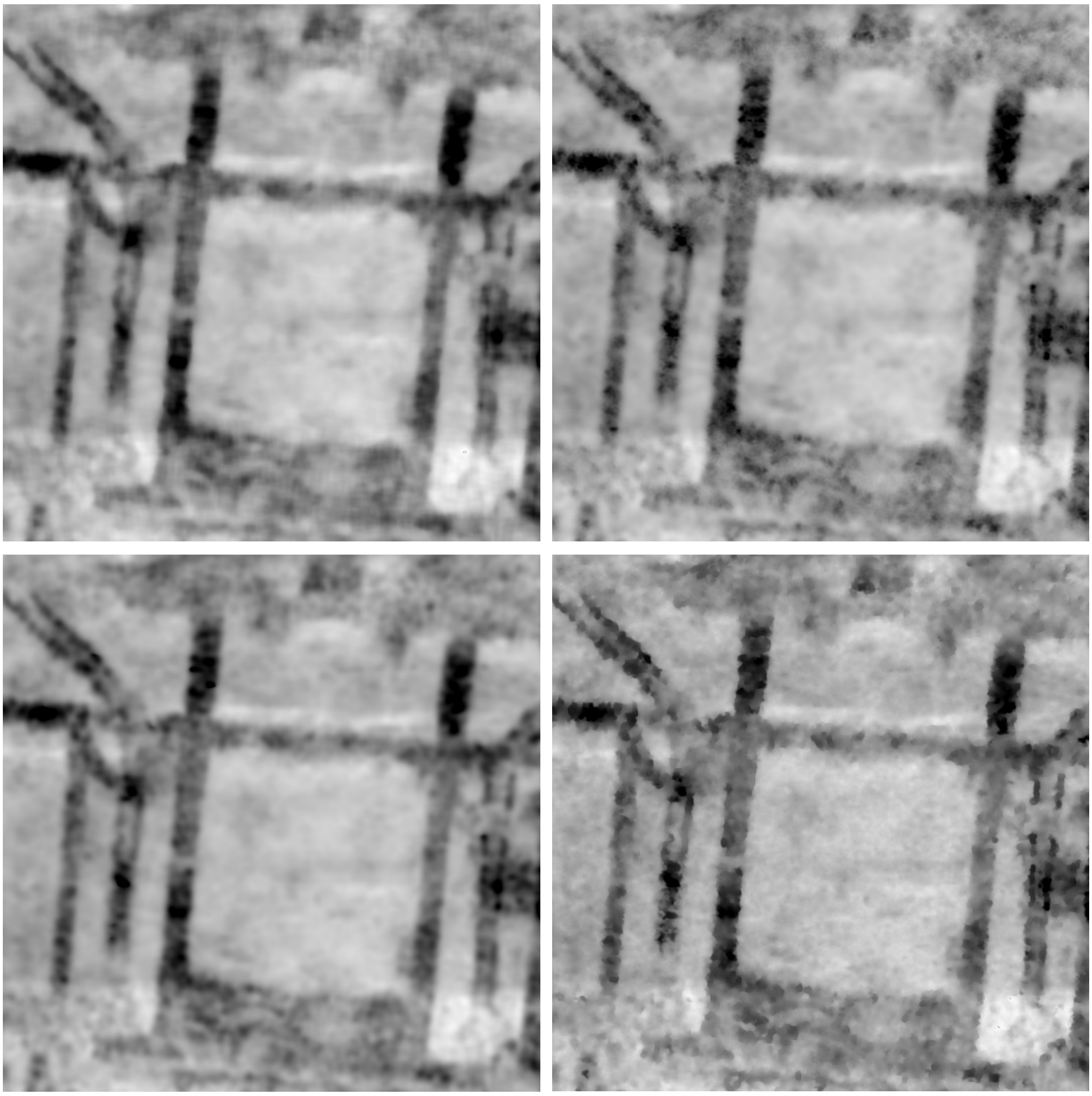

Fig. 45. Filtering results of a 3D median filter of kernel size 5 (top left), a bilateral filter (top right), an edge-enhancing anisotropic diffusion filter (bottom left) and a TV-L1 filter λ=0.75 (bottom right).

The TV-L1 filter generally resulted in the best delineation of archaeologically relevant features regarding preservation of boundary surface detail. All other filters tend to blur the data to some extent as can be seen in the corresponding volume visualisation results in Fig.46. However, we found that the smoother, slightly less detailed results of the bilateral filter to be better suited for 3D printing of foundation wall models obtained by using an iso-surface extraction algorithm.

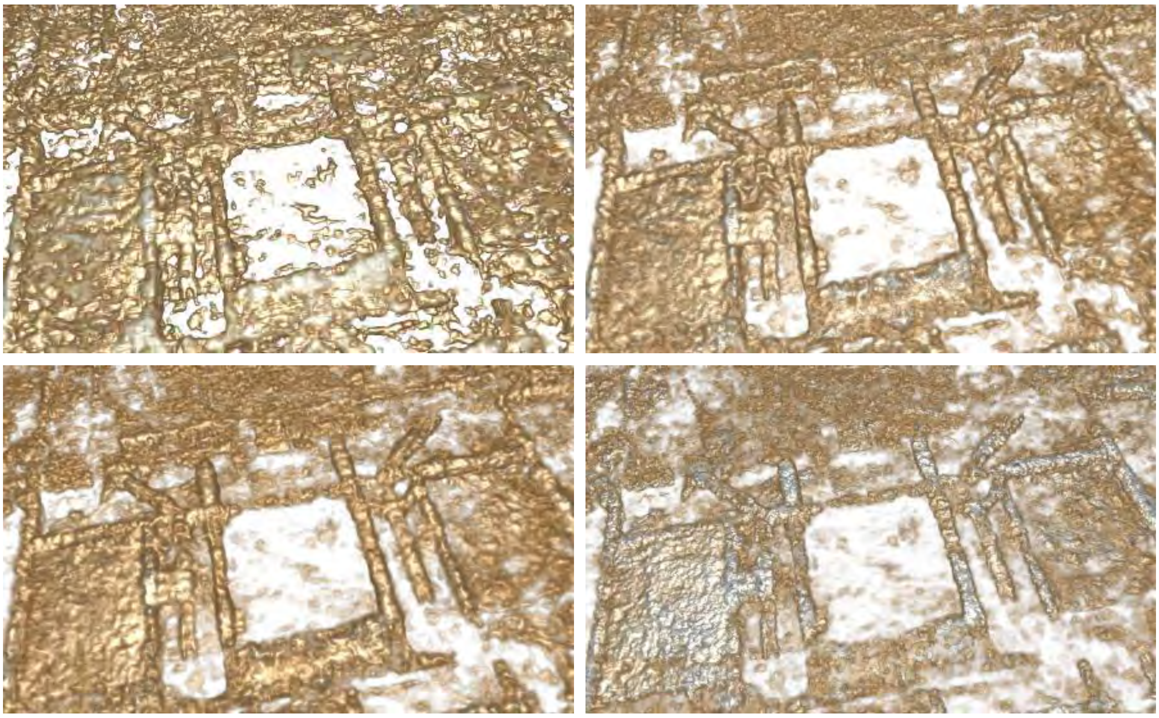

Fig. 46. Direct volume rendering of GPR datasets filtered with a 3D median filter of kernel size 5 (top left), a bilateral filter (top right), an edge-enhancing anisotropic diffusion filter (bottom left) and a TV-L1 filter λ=0.75 (bottom right). The outlines of the foundation walls, sewerage ducts and stone floors are clearly visible in all images. The blur level introduced by the median filter seems to be generally higher and respecting the shape edges of archaeological features to a lesser extent. The TV-L1 filter largely avoids blurring of structure boundaries.

8.2 Structure filters

Another possibility investigated in 2020 were 3D image filters to highlight structures based on their shape. We were particularly interested in filters automatically depicting contiguous elongated, tube-like structures in GPR datasets, which are characteristic for many manmade changes like building foundations or ditches. GPR datasets from archaeological sites with multiple settlement periods can be overly complex, since building remains may be overlapping, incomplete and overlapping with other finds. Edge-preserving smoothing does not resolve this problem and 3D visualisation are still cluttered.

Integration of the result of ranking the orientation responses of path operators (RORPO) filter, initially developed for detection the vasculature in medical 3D data, supports the selective visual depiction of thin curvilinear structures. The example in Figure 47 shows 3D visualisations of a small region of the GPR dataset recorded at the famous Viking site in Birka. With and without RORPO. The foundation of the Viking house is hard to see amid numerous geological and manmade structures with similar radar absorption properties. The filter selectively increases the visibility of all similar elongated structures, thereby slightly decreasing clutter.

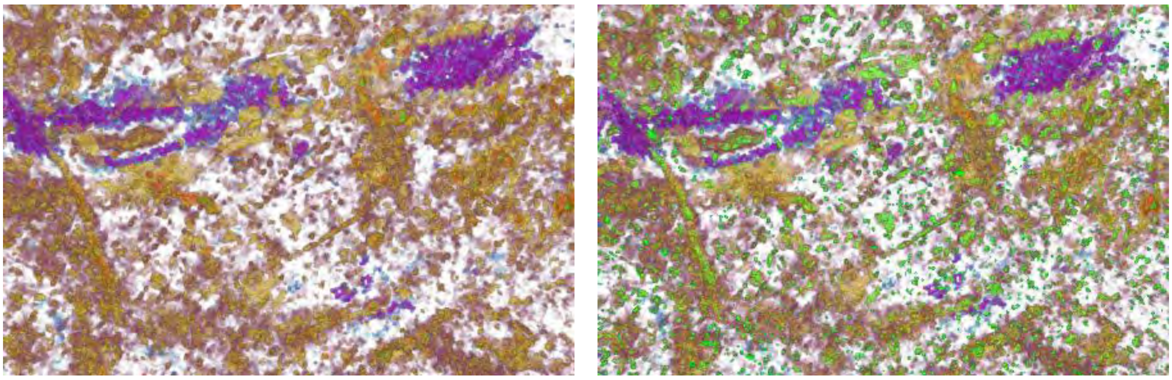

Fig. 47. 3D visualisation of a complex GPR dataset from the Viking site of Birka.

8.3 Segmentation

In addition to filtering techniques the applicability of 3D image segmentation algorithms to GPR data has been further investigated. In contrast to filters, segmentation techniques support the explicit extraction of a particular structure in the dataset. Due to the - in contrast to medical image processing - diverse and unknown shapes of potential interest, the focus was put on interactive techniques, leading to a segmentation software tool extracting the target object based on a manually drawn example regions. The tool is based on a variational formulation of the segmentation problem, which can be efficiently computed on modern graphics cards for practical dataset sizes.

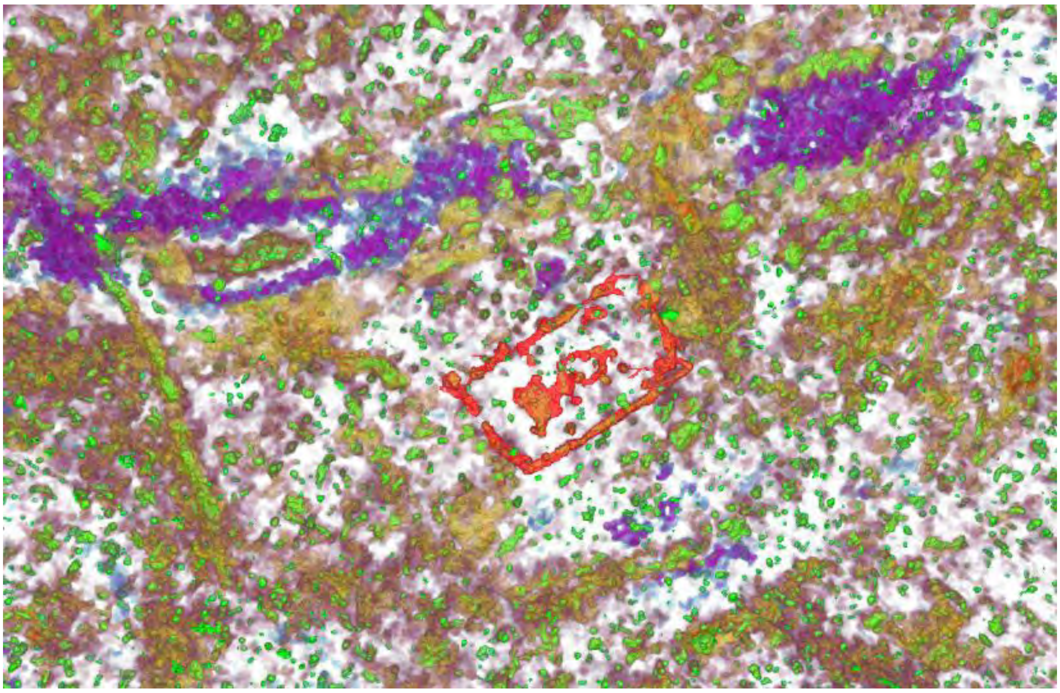

Fig. 48. Visualisation of the remains of a Viking house segmented in a GPR dataset using an interactive algorithm (red) embedded in the GPR 3D visualisation. The floorplan and architectonic details like the location of the entrance, pillars, and an oven are clearly visible.

Fig.8 shows an example from the Birka dataset. The higher degree fidelity to extract various structures using segmentation algorithms supports using segmentation tools for interpretation. An interpretation based on segmentation, ideally resulting in a non-overlapping labelling of each dataset voxel, would be a novel leading to results matching data evidence after decay/destruction erosion, etc., while current interpretation approaches try to reconstruct the state when a building was still in use.

8.4 Classification

GPR images appear to be noisy with the local noise pattern also referred to as texture depending on the soil or man-made structure region. This suggests that it should be possible to extract structures of archaeological interest by performing a classification based on a set of image features representing such noise pattern changes. Therefore, we investigated texture features based on the grey-level cooccurrence matrix (GLCM) and the grey-level run length matrix (GLRM) like the Haralick texture features, which have been successfully used in many fields, including remote sensing and medical imaging.

Unfortunately, this approach was not successful in the sense of consistently resulting in more than two separable clusters or object classes using clustering like k-means, maximum likelihood, and DBSCAN. Different texture features will be investigated as well as more powerful clustering and classification approaches. From the visualisation perspective, we observed that 3D visualisations of some features computed from the GLCM or GLRM seem to be better suited to visualize, e.g., hypocausts and other floor structures in Roman buildings than the original absolute amplitude dataset (Fig. 49).

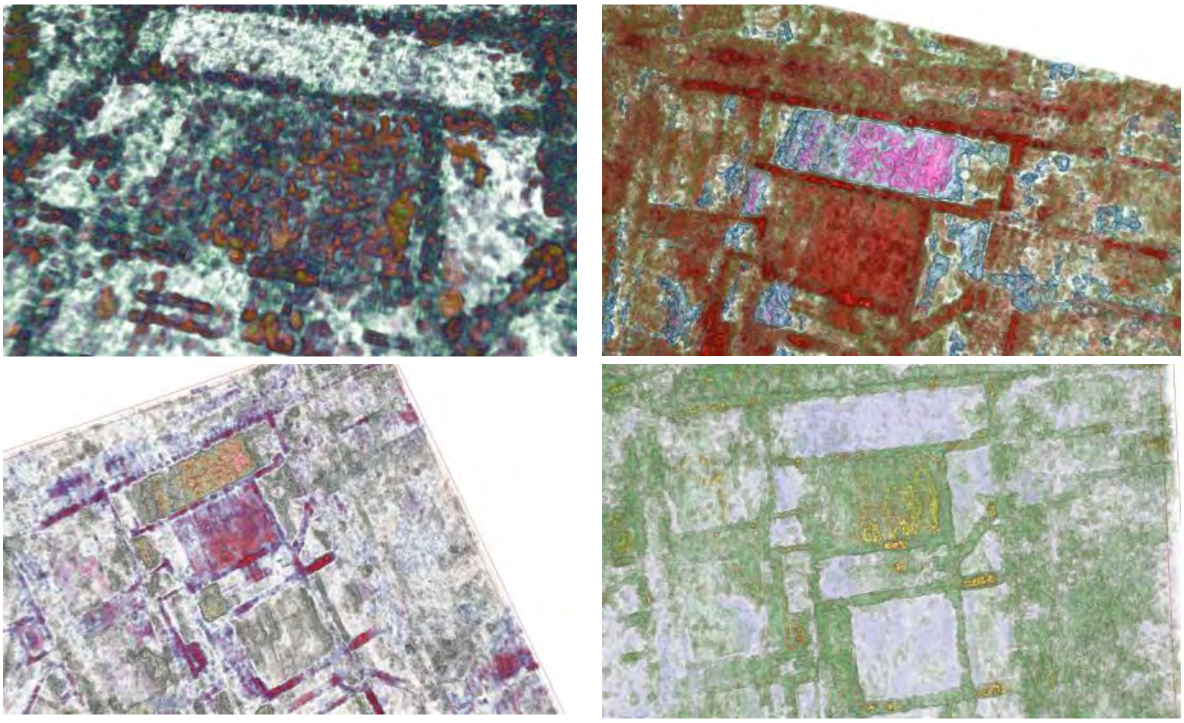

Fig. 49. 3D visualization based on features computed from the amplitude dataset grey-level cooccurrence matrix (GLCM). Some for these features seem to result in better visibility of the inner structure of, e.g., floor structures in the Carnuntum forum dataset.

The need to be able to compute different features for the automated analysis of GPR data also led to the development of a modular software tool, which computes filters, features, and clustering using the power of modern GPUs. It also supports the computation of attributes adopted from seismic data analysis, such as coherence measures, which will be used for visualisation and semi-automated feature extraction in the future.

8.5 Machine learning

At present machine learning based on deep convolutional neural networks (DCNNs) are extremely popular, not to say it has some hype around it. Indeed, the are very capable and versatile to solve many different problem classes, most prominently image recognition, natural language processing with some applications in archaeology like cuneiform writing detection.

In 2020 we looked at possible applications of DCNNs leading to a higher degree of automation in prospection data analysis together with experts from Graz University of Technology with the conclusion that it will be possible to use these techniques for various questions ranging including the detection of archaeological structures, classification of GPR dataset regions, and segmentation.

Successful application of DCNNs relies on the availability of sufficient verified training data. Even though LBI-CFI and its partner have access to GPR data covering square kilometres all over the world this is nothing compared to the number of images of dogs, cats, and so on available on the internet for training object detection networks. Tasks beyond detection like classification or segmentation would even require accurate interpretations matching the data and verified based on excavations.

Despite these circumstances we will follow up on the topics, focus on a particular detection problem like Roman foundation walls and try to employ data augmentation techniques to compensate the limited training data.

9 Reconstruction (REC)

The combination of fused prospection data is representing key elements of the buried stratification. The research topic INT will deliver 2D and 3D interpretative models of these archaeologically relevant subsurface structures, which form the basic input for the research topic Reconstruction (REC). To determine the depth and the size of magnetically detected archaeological structures or objects a new algorithm was developed and integrated into the software module ApMag based on the reconstruction of near-surface magnetic dipole anomalies. The software developed earlier for the reconstruction of circular ditch enclosures based on 3D inverse modelling of magnetic data has been adapted for the reconstruction of various other archaeological features.

Another focus for the research topic REC is the development of transparent and comprehensive workflows to produce architectural and landscape reconstruction models in direct relation to the prospection data. These models are developed in a way that the basic background data, analogies, and assumptions are referenced, and respective uncertainties are modelled and visualized. Several virtual reconstructions have been realised together with partners 7reasons and ArcTron3D to be used for public presentations on scientific events using VR glasses or for media projects like major TV productions (see chapter 12.2) and exhibitions e.g., at the Keltendorf Schwarzenbach in Lower Austria.

Piber – Church St. Andreas

Among the many historical buildings that are located on the grounds of the Federal Stud Piber and that are being documented digitally in the framework of the Piber Digital project (see chapter 14.1) is the church of St. Andreas. The first stone church building, dates from the 11th century. The basic building, erected as a Romanesque country church, was rebuilt and extended several times over the centuries. Together with partner ArcTron3D the internal and external structure of the church was documented using aerial (RiCOPTER) and terrestrial laserscanning (RIEGL VZ-400i). The combination of the datasets resulted in a high-resolution digital 3D model of the complete church with all interior rooms (Fig. 50). The virtual model has been made available for the public on YouTube (https://youtu.be/2T9Fa6CgZec).

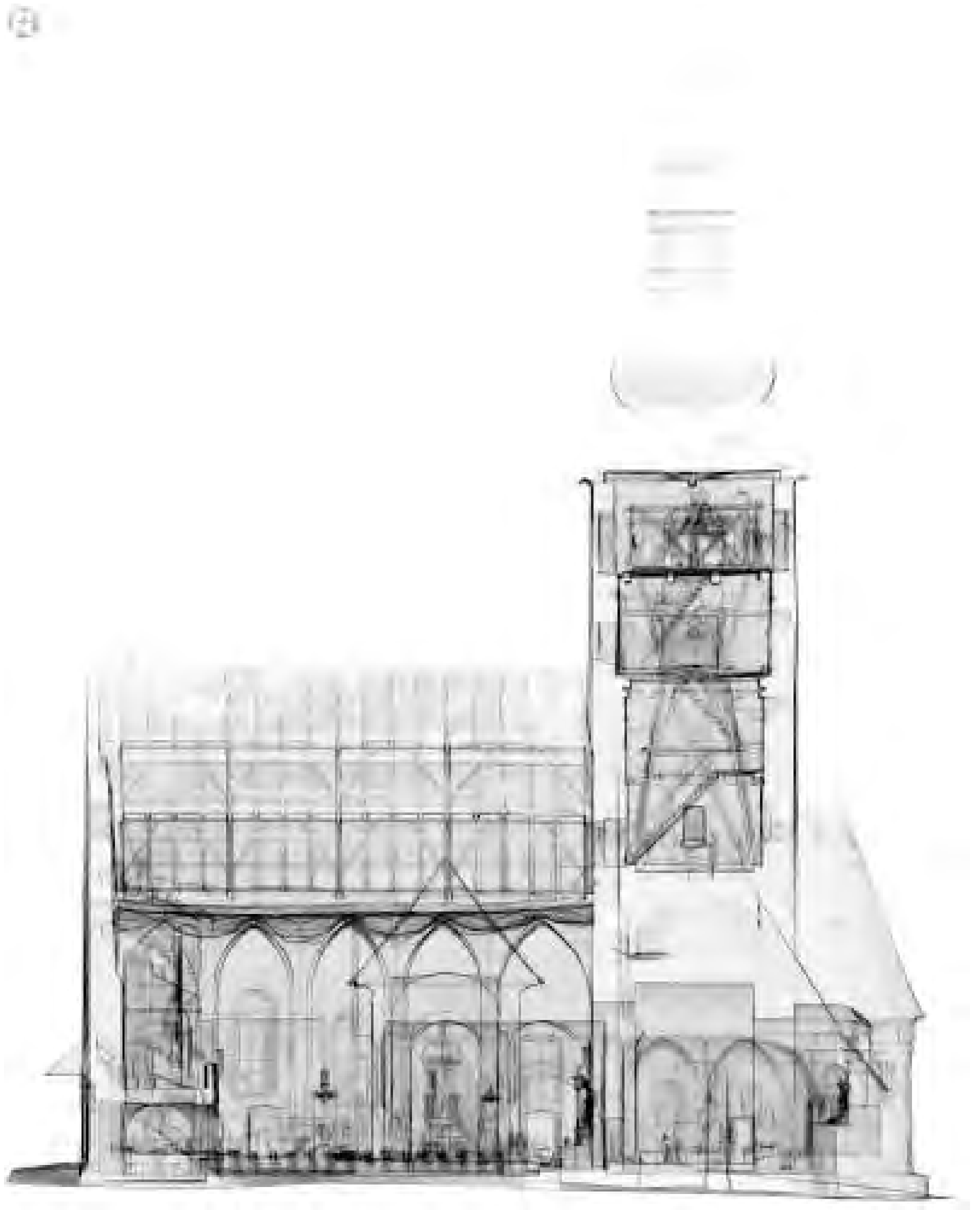

Fig. 50. Combined TLS and ALS data of the church St. Andreas (side view).

Keltendorf Schwarzenbach

The institute’s exhibition in Schwarzenbach is under ongoing development. The museum container which includes a large projection mapping installation was opened in 2019 and was well received. In 2020, the Corona pandemic caused a postponement of the projection mapping installation to 2021.

Apart from the creation of multi-phased 3D models of the appearance of the Schwarzenbach hill site in SketchUp, which is used for explanatory projection mapping in the exhibition, the creation of a virtual reconstruction of the wider landscape in the Unity game engine was attempted.

10 Simulation (SIM)

In general, simulation is used for the scientific modelling of natural or human systems 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.

10.1 Open-source desktop planetarium *Stellarium*

A specific focus is set on the integration of architectural and landscape models into the software Stellarium which is able to simulate the sky through time for archaeoastronomical studies. Georg Zotti is co-developer of the popular Stellarium open-source desktop planetarium (https://stellarium.org). 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. Stellarium's quarterly releases are downloaded by approx. 300.000-700.000 users, mostly by amateur astronomers, but also by researchers of cultural astronomy. An extended description of the program has been published in the Journal for Skyscape Archaeology. Despite cancellation of all "presence" conferences or public appearances due to the Corona pandemic, Georg presented Stellarium at the Annual Meeting of the German Astronomische Gesellschaft, in a lecture in the SOPHIA online Keynote Lecture Series (42 participants) and in an Invited Talk at IAUS367. The recording has been seen on YouTube by over 700 users. After IAUS367, Georg was invited to give a 1-hour presentation as one of 4 "Chinese New Year" talks by the Virtual Observatory of the Chinese Academy of Sciences (China-VO), held on Feb. 1st, 2021 with a live audience of about 2500.

During 2020 an error in the source paper for nutation correction could be identified by an external reporter and was corrected, so that version 0.20.3 (released September 27, 2020) is the first version to agree (within rounding accuracy) about the beginning times of the seasons with "official" sources given to the minute. One of the two final known astronomical deficiencies, accurate orientation and rotation of planet axes, has seen some progress, but is still not solved due to work overload and the fact that such concentrated work can only be performed in weeks of vacation or similar quiescence (around New Year), the necessary accumulated weeks of which had to be thrown away due to Corona pandemic regulations. However, in early 2021 this problem was finally solved, to be released in March 2021.

Stellarium still has a known issue related to high-accuracy coordinates, and will have to undergo a major upgrade of its underlying Qt5 C++ framework after the release of Qt6. After that, some more attention must also be given to its functionalities for representation of "skycultures" (constellations and related features) of cultures around the globe.

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 and published 2020 in SDH. In an example application, 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 quadrant 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, and astronomical data retrieved, using its RemoteControl HTTP API. 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 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 do not 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.

11 Spatio-temporal reasoning (STR)

11.1 Harris Matrix Composer (HMC)

In 2020 the LBI ArchPro continued to offer licenses for the Harris Matrix Composer v2.0b and received 63 requests from 20 different countries (Fig. 51). Thus, based on the number of requested licenses, 2020 was the second-best year after 2014 since the first release of HMC in 2008 (Fig. 52). An interactive overview of the organizations that have acquired an HMC license in the past 12 years can be found under https://harrismatrixcomposer.com/stats/organizations.html.

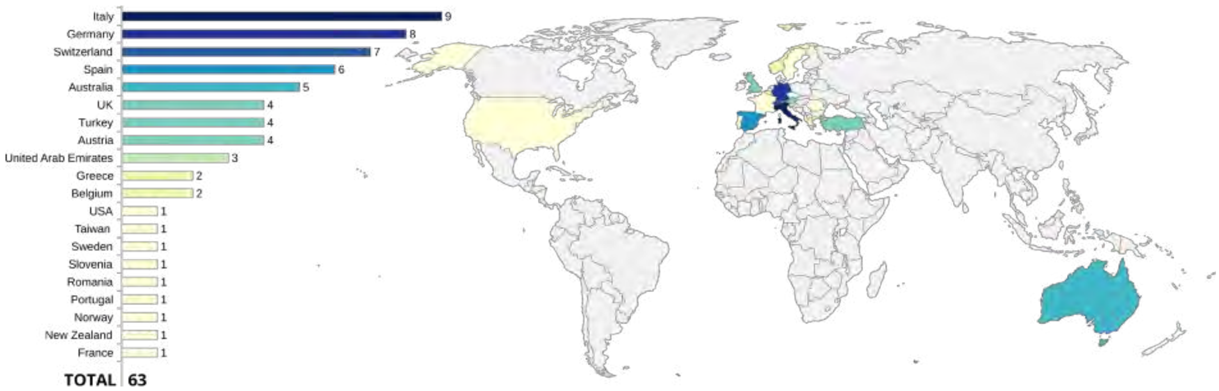

Fig. 56. HMC license requests in 2020.

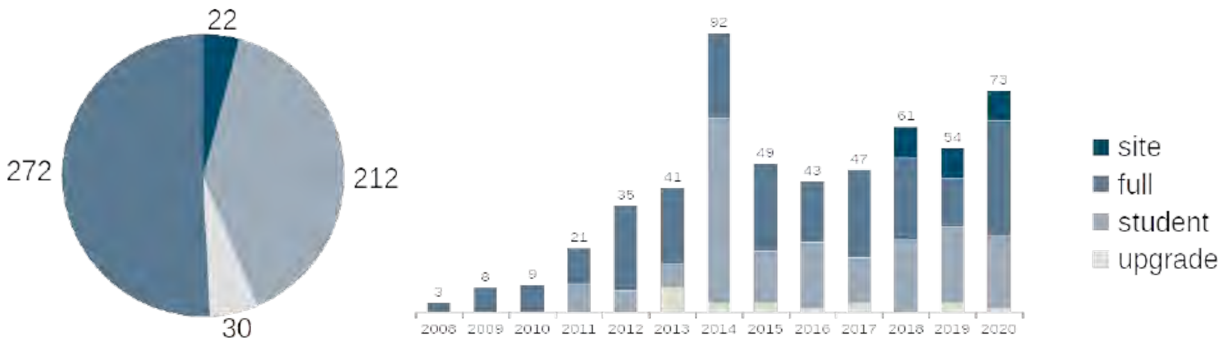

Fig. 57. Total of HMC licenses since 2008. Site licenses are multiplied by a factor of 10. Student, Full and Upgrade licenses have a factor of 1.

The HMC v2.0b for MacOS was also ported to the most recent releases MacOS Catalina (version 10.15) and MacOS Big Sur (version 11).

11.2 Harris Matrix Composer Plus (HMC+)

In 2020, the main focus was on refactoring the code base and on developing the interface to ArcGIS Pro. A new API layer was developed to provide a well-defined interface for future extensions. To simplify the communication between HMC+ and external services, the server code was rewritten in Kotlin using gRPC, a modern open-source high-performance framework for remote procedure calls. The plugin for ArcGIS Pro will be available in the summer of 2021.

Furthermore, two new tools have been developed:

HTML Exporter Tool: The tool can be utilized to export a matrix and a time model as a stand-alone HTML file. The HTML file contains an interactive viewer based on the D3 JavaScript library. This allows third parties who do not own the Harris Matrix Composer to explore the matrix (Fig. 53).

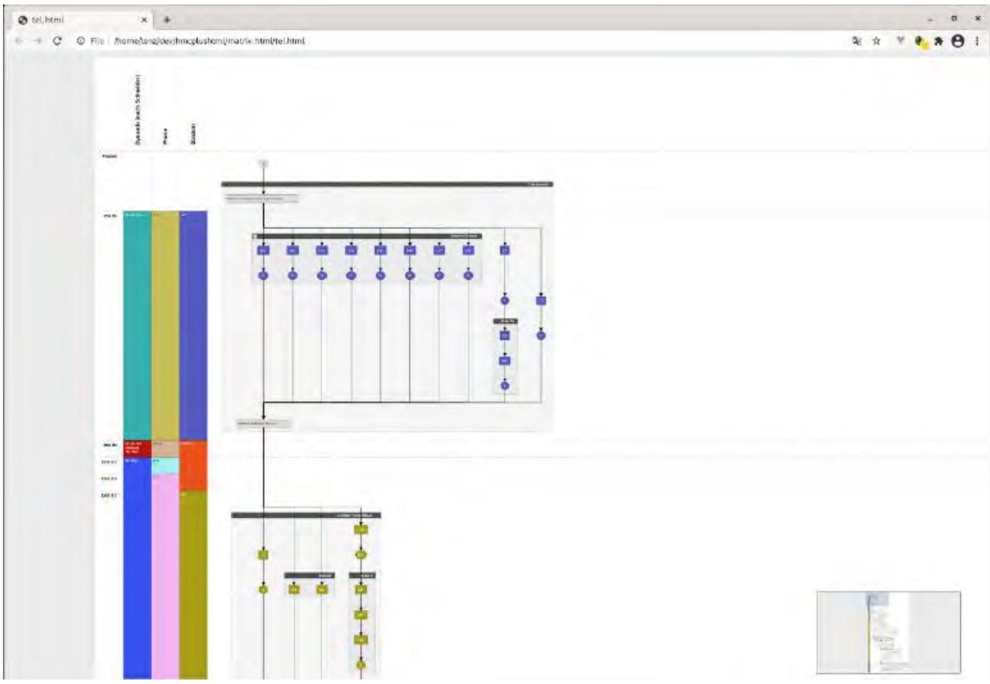

Fig. 58. A Harris Matrix exported as stand-alone HTML file.

Stratigraphic Unit Data Verification Tool: A prototype of the "Stratigraphic Unit Data Verification Tool" was implemented to support the verification process (Fig. 54). It simplifies the cross-checking of the constructed Harris Matrix with the paper-based data sheets collected during excavation. The main goal of the tool will be to digitize all the information given on the datasheet. This includes descriptions of topography, soil, archaeological features, and other important information such as Munsell Codes or sketches of the deposit. This data can then be transferred into a geodatabase with the help of the GIS-plugin.

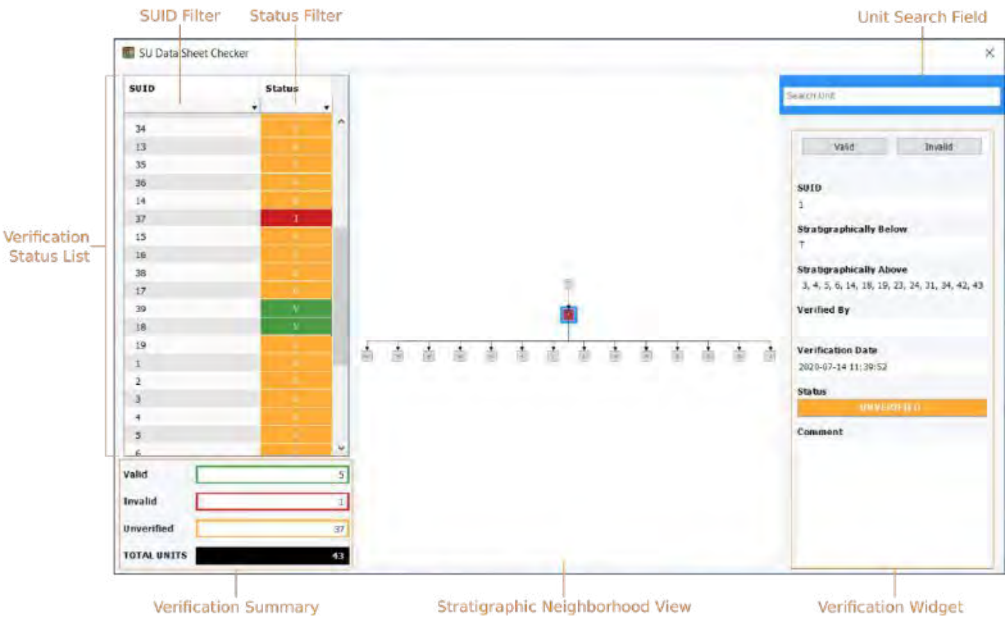

Fig. 59. The verification process of the stratigraphic neighbourhood for a deposit.

Due to the Covid19 pandemic, the open beta-testing phase and the release of HMC+ had to be postponed to 2021.

11.3 Proof of Concept - Horse Mating Chart

During the fieldwork in Piber, the idea was born to implement a tool that visualizes the pedigree of all Lipizzaner horses that have ever lived. For this purpose, we used the capabilities of HMC+ to manage and visualise spatio-temporal data. We implemented a temporal analysis tool to compare the lifespans of horses and to find out which horses lived at the same time (Fig. 55).

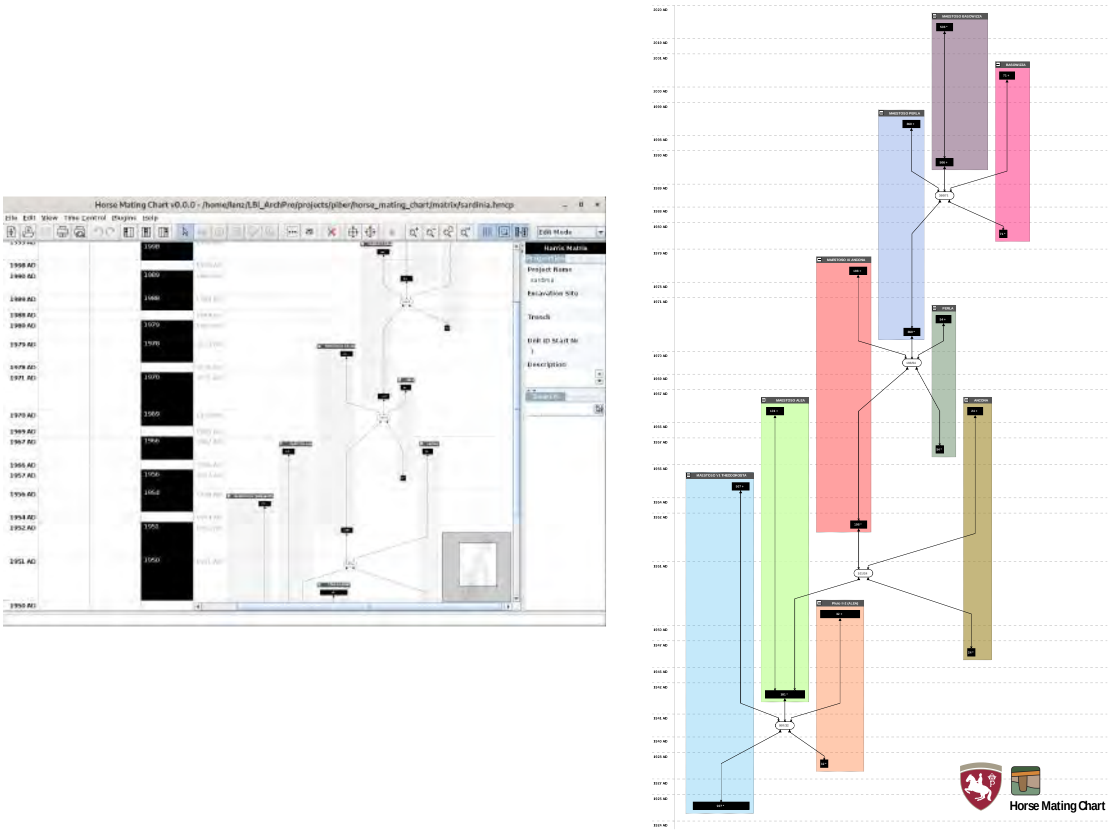

Fig. 55. This a prototype of HMC+ showing a section of the pedigree of the Lipizzaner stallion „Maestoso Basowizza".

12 Dissemination and awareness (DISS)

12.1 Press releases

Discovery of a massive, Late Neolithic Pit Structure at Durrington Walls, UK

In June 2020, a joint international press release was published by a consortium of archaeologists as part of the Stonehenge Hidden landscape Project, led by the University of Bradford and the LBI ArchPro, announcing the discovery of a massive 2km-wide circle of prehistoric shafts around the 'super henge' at Durrington Walls and the famous site at Woodhenge. Within the project, a series of massive geophysical anomalies, located south of the Superhenge Durrington Walls three kilometres from Stonehenge, were identified by the magnetic survey undertaken by the LBI ArchPro. The structures have been carbon dated to about 2500BC. The press release triggered a worldwide media response (see Appendix "Media coverage 2020").

Viking Age ringforts in Denmark

In a cooperation with the Kurier Zeitung, two full-page features on the LBI ArchPro's research project on Viking Age ringforts in Denmark were released in the beginning of February 2020 (see Appendix "Media coverage 2020").

12.2 TV productions

nano – 20.10.2020 (3sat)

During the excavation in Kleinhadersdorf various efforts were made to share the results and current scientific findings with the interested public. Many representatives of local print media (see Appendix "Media coverage 2020") visited the excavation during different stages of work and subsequent wrote articles about the research in Kleinhadersdorf.

A television coverage of the excavation aired on the channel 3Sat as a seven-minute-long episode of the transnational popular science documentation series "nano" titled "Auf den Spuren der ersten Bauern" (available on: https://www.3sat.de/wissen/nano/201020-bauern-nano-104.html).

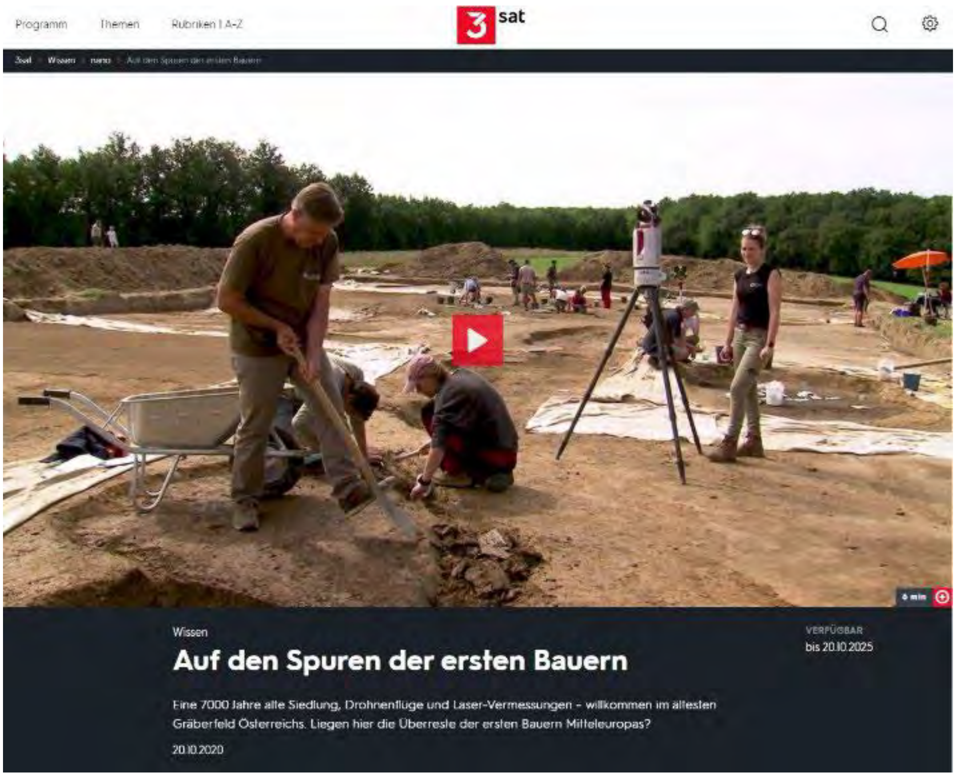

Fig. 56. Screenshot of the "nano"-broadcast on Kleinhadersdorf.

An internet presence for this project was realized through an ESRI Story Map (Kleinhadersdorf, uncovering a Neolithic house from the first settlers in Austria) and the homepage of the LBI ArchPro partner firm *Arc*Tron^{3D} who facilitated the project through airborne 3D-documentation with photogrammetric drone and ultra-light paraglide tricycle. In addition, sizable social media coverage was realized through an instagram profile of the excavation (Loessventures- https://www.instagram.com/loessventures/).

Verstehen Sie Spaß? - 31.10.2020 (ARD)

Two contributions with the involvement of the LBI ArchPro were developed and produced in the very popular program of the ARD (D) „Verstehen Sie Spaß?“, where people work with hidden cameras, whereby the institute reached an audience of several million viewers.

12.3 Federal Stud Piber dissemination project

In November 2020, a joint project with the Spanish Riding School was started at the Federal Stud Piber which aims at the complete digitization of the Stud and its surrounding area (Fig. 57; see also chapters 2.4 and 14.1). The collected data will provide the digital basis for corresponding implementations of annual exhibitions on prehistoric and historical equestrian cultures and new guiding concepts with the help of Augmented and Virtual Reality applications. In addition to these annually changing exhibitions, permanent exhibitions are also planned in the Museum of the Federal Stud, with a special focus on the digitization of entire landscapes and historical buildings. In the castle of Piber there are further exhibition rooms available, which are to be designed together with the LBI ArchPro to integrate adequate multimedia, augmented and virtual reality applications into the exhibition concept.

A dedicated project website has been designed by the LBI ArchPro in collaboration with the Spanish Riding School: https://piber-lbiarchpro.org.

The planned cooperation projects have a duration of five years going beyond the duration of the LBI ArchPro’s concluding funding period and emphasize the institute’s commitment for the continuation of dissemination and awareness activities with a high international visibility.

Fig. 57. Terrestrial Laserscanning at the Federal Stud Piber.

12.4 Scientific publications and presentations 2020

In October 2020, a new website was launched to provide a convenient overview of all scientific publications of the LBI ArchPro. The website is available at https://publications.lbi-archpro.org/.

Articles

Doneus, Michael; Mandlburger, Gottfried; Doneus, Nives (2020): Archaeological Ground Point Filtering of Airborne Laser Scan Derived Point-Clouds in a Difficult Mediterranean Environment. In: *Journal of Computer Applications in Archaeology* 3 (1), S. 92–108. DOI: 10.5334/jcaa.44.

Doneus, Nives; Miholjek, Igor; Džin, Kristina; Doneus, Michael; Dugonjić, Pavle; Schiel, Hannes (2020): Archaeological Prospection of Coastal and Submerged Settlement Sites. Re-Evaluation of the Roman Site Complex of Vižula, Croatia. In: *Archaeologia Austriaca* 104, S. 253–281. DOI: 10.1553/archaeologia104s253.

Filzwieser, Roland; Eichert, Stefan (2020): Towards an Online Database for Archaeological Landscapes. Using the Web Based, Open-Source Software OpenAtlas for the Acquisition, Analysis and Dissemination of Archaeological and Historical Data on a Landscape Basis. In: *Heritage* 3 (4), S. 1385–1401. DOI: 10.3390/heritage3040077.

Gaffney, Vincent; Baldwin, Eamonn; Bates, Martin; Bates, C. Richard; Gaffney, Christopher; Hamilton, Derek et al. (2020): A Massive, Late Neolithic Pit Structure associated with Durrington Walls Henge. In: *Internet Archaeology* 55. DOI: 10.11141/ia.55.4.

Gugl, Christian; Humer, Franz; Radbauer, Silvia; Schindel, Nikolaus; Wallner, Mario; Zabehlicky, Heinrich (2020): Archäologische Prospektion und Ausgrabungen in der Flur Gstettenbreite: Gräber und Straßenverläufe im westlichen Vorfeld der Carnuntiner Zivilstadt. In: *Carnuntum Jahrbuch* 2019, S. 11–53. DOI: 10.1553/cjb_2019s11.

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13 Training and teaching (TRAIN)

13.1 Internal training

RiCOPTER-Training

In summer 2020, a selected team of the LBI ArchPro and Martin Schaich – CEO of the partner institution ArcTRON3D - attended a 5-day RiCOPTER-training by manufacturer RIEGL LMS at Horn (Fig. 58). Matthias Kucera, Gerhard Stüttler and Martin Schaich were trained as pilots for the newly acquired drone and Andreas Lenzhofer, Geert Verhoeven and Georg Zotti as operators.

Fig. 58. RiCOPTER training with RIEGL LMS.

13.2 University field school at the Linear Pottery settlement of "Kleinhadersdorf"

Results of large scale archaeological geomagnetic surveys (32.3 ha, LBI ArchPro 2017-2018) further proved the importance of the Kleinhadersdorf Linear Pottery settlement site and made a following precise trench placement of the research excavation 2020 possible. The aim was to investigate the special stratification of this site, which encompasses almost 5 ha, to evaluate the quality of ground conservation, to examine the dating of house structure with a focus on settlement continuity and to gain relevant information regarding settlement and economic archaeological issues. Additionally, the scientific analysis of the artefacts recovered during the three-year excavation project in Kleinhadersdorf (2020-2022) will shed light on the presumed contemporaneity of the site with the adjacent burial ground, which had been investigated in the 1930s and 1980s.

The first research excavation and field school were carried out in collaboration with the University of Vienna over the course of four weeks in summer 2020 (see also chapter 13.3 “internships”). During the excavation of an 1101 m² spanning trench the structure of one specifically selected house was exposed completely (Fig. 59). Complementary susceptibility measurements were undertaken after the topsoil was removed and an almost perfect match with the magnetic und susceptibility data was revealed. Analysis of the finds corroborated a periodisation of the site into the Early Neolithic Period and especially the Linear Pottery culture. The excavated surfaces were digitally documented by image-based modelling and laser scanning and generated a new set of data, which again led to a significant improvement in the understanding of the site.

Fig. 59. Left: View of the excavation trench at Kleinhadersdorf. Right: Student assisting with the documentation process.

13.3 Internships

In 2020 the LBI ArchPro offered several opportunities to students to gain research and work experience in the fields of archaeological prospection and virtual archaeology. The interns were guided by the dedicated LBI ArchPro team as they worked on their respective internship projects.

13.3.1 Archaeological excavation and 3D documentation of archaeological excavation data

During the field school at Kleinhadersdorf a team of advanced-level archaeology students of the University of Vienna supported the LBI ArchPro scientific staff with various tasks such as the 3D documentation of the excavation and assisted in teaching and instructing undergraduate field school students on site. The archaeological field assistant team included Miriam Feichtinger, Janine Gaida, Valentina Graf, Barbara Jell, Simon Jenner und Matthias Löffler.

Leon Schlund and Tatjana Reuss completed a 4-week school student’s internship funded by the FFG *Talente* programme actively participating in all excavation activities with a focus on the digital documentation, in situ measurements of chemical and physical parameters of archaeological deposits and sampling.

Supervisor: Wolfgang Neubauer

13.3.2 Archaeological geophysical prospection

During her FEMtech internship Katharina Riederer was trained in the acquisition, processing and integrated interpretation of archaeological prospection data using motorized magnetometer- and GPR-systems and GIS-based techniques (e.g., Denmark interpretation workshop, see chapter 4.1).

Supervisor: Wolfgang Neubauer

13.4 University lectures

Table 1 lists the academic lectures and courses held by LBI ArchPro staff at the University of Vienna in 2020:

Wolfgang Neubauer	Summer 2020	• 060092 LP Lehrgrabung 2 (Kleinhadersdorf/NÖ, Linearbandkeramik-Siedlung • 060096 SE Seminar Abschlussarbeit
	Winter 2020	• 060053 SE Bachelorseminar Urgeschichte • 060060 SE Seminar Abschlussarbeit I
Immo Trinks	Winter 2020	• 060041 VO Einführung zu archäologischen Prospektionsmethoden • 060077 VO Naturwissenschaftliche Methoden der Archäologie: Archäometrie • 060101 VO Magnetische archäologische Prospektion - Magnetic archaeological prospection • 060104 UE Übung zur magnetischen archäologischen Prospektion
Matthias Kucera	Summer 2020	• 060044 UE Experimentelle Archäologie in der Praxis • 060069 VO Naturwissenschaftliche Datierungsmethoden
	Winter 2020	• 060080 VO Experimentelle Archäologie
Klaus Löcker	Summer 2020	• 060041 KU Kurs zu Grundlagen der Vermessung und der Stratigraphie
Geert Verhoeven	Winter 2020	• 060107 KU Image-based modelling for archaeology
Michael Doneus	Winter 2020	• 060045 UE GIS-Anwendungen in der Archäologie • 060048 UE Luftbildarchäologische Interpretation • 060059 UE Vertiefende Übung zur wissenschaftlichen Praxis • 060060 SE Seminar Abschlussarbeit I • 060067 UE Flugzeuggetragenes Laserscanning (LiDAR) für Archäolog*innen

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

In October 2020, Geert Verhoeven gave an online lecture ("Archaeological Remote Sensing") in the Master curriculum "Specifieke onderzoekstechnieken" at the University of Antwerp.

14 Third party funded research projects

14.1 Piber Digital

Short description of project: Third party funded digitalization project at the Lipizzaner Stud Piber with the Spanish Riding School
Short description of sites: historical buildings; pasturelands in Styria
Datasets: ALS; TLS; MAG; GPR; historical sources
Keywords: intangible UNESCO cultural heritage; novel digitization methods; novel methods for the dissemination of cultural heritage; large-scale geophysical prospection
Benefits: safeguarding of and raising awareness for UNESCO cultural heritage; non-invasive investigation of archaeological sites; promotion of regional economic development and cultural tourism; close collaboration with RIEGL LMS

Since November 2020, the Spanish Riding School and the LBI ArchPro have been collaborating on an ambitious research project at the Lipizzaner Stud Piber in Styria, Austria (Fig. 60). The research initiative of the management of the Spanish Riding School has the goal of transforming the intangible cultural heritage of mankind into a living sustainable resource for shaping the future development of the stud, strengthening regional economic development, and promoting cultural tourism at the birthplace of the Lipizzaner.

The cultural heritage in Piber will be digitized and transformed into virtual space using high-resolution laserscans and photography. The newly acquired RiCOPTER UAV with integrated laser scanner (see chapter 2.4) is playing a crucial role in the efficient digital documentation of the historical buildings and the landscape around the stud. The extensive and archaeologically rich surroundings, which have been unaffected by agricultural activities for hundreds of years, will also be investigated using non-invasive geophysical prospection methods. First GPR and magnetometry surveys have been conducted in the vicinity of the church St. Andreas and on the stud’s vast pasturelands. The fieldwork is ongoing.

Fig. 60. Overview of the Federal Stud Piber with Piber castle and church St. Andreas.

This project aims to ensure the long-term preservation of this unique cultural heritage, to make it accessible to all and to use it to promote regional, national and European identity, thus securing it sustainably for future generations. In close cooperation with the Spanish Riding School and the stud authorities, a concept for the redesign of the existing museum and the exhibition rooms in Piber Castle is to be realized (see chapter 12 "DISS").

14.2 Switzerland

Burg Forstegg

Short description of project: Third party funded geophysical prospection project in collaboration with the Kantonsarchäologie St. Gallen

Short description of site: medieval castle in the Rhine valley

Datasets: GPR; ALS; historical sources

Keywords: large-scale geophysical prospection; GPR survey; medieval castle

Benefits: gaining new knowledge on the layout a medieval castle and formerly unknown surrounding structures by the combination of geophysical and remote sensing datasets with historical sources

During the summer campaign in Switzerland in late August 2020 the LBI ArchPro investigated a late medieval castle in the Rhine valley, Burg Forstegg, which is situated some 2 km south of the small township of Sennwald (canton St. Gallen). An area of about 7.000 square metres surrounding the ruined castle has been prospected with two GPR systems, the MIRA 1 and the 3-channel 500 MHz handheld. In addition to the geophysical survey, the ALS data of the area was also interpreted.

The GPR survey has been carried out in the preparation of a small test excavation by our partner Kantonsarchäologie St. Gallen in the run-up of the renovation of the whole complex. It was possible to identify a connecting wall between the castle and the armoury and to find foundation walls of the former stables and the wine press and cellar as well as an additional unknown building outside of the entrenchment. By the joint interpretation of the GPR data, the ALS data and historic maps and pictures, the formerly unknown location and general layout of the past entrenchment with its bastions and the massive backfilled ditch along its southern front, where later a garden had been built over, could be identified (Fig. 61).

Fig. 61. Interpretation map of the prospected area around Burg Forstegg.

Sargans

Short description of project: Third party funded geophysical prospection project in collaboration with the Kantonsarchäologie St. Gallen following an excavation campaign
Short description of site: Roman bath complex on a development site
Datasets: GPR; excavation data
Keywords: GPR survey; Roman period; Switzerland
Goal: supplementing the excavation data of a Roman bath complex using GPR

Following up the survey of the Roman villa of Sargans in 2017 the LBI ArchPro was able to investigate a smaller area (of about 1.400 square metres) in the place of the former bath building in late August 2020. This area has been inaccessible before due to a modern building that has been built over it and demolished just recently. The GPR survey was conducted using the 3-channel 500 MHz handheld system. The Kantonsarchäologie St. Gallen has been carrying out an excavation in that area before our survey in order to find and document the remains of the Roman bath and connected buildings. The aim of the survey was to identify additional walls and building structures outside the excavation trenches. Unfortunately, the geophysical contrast between the soil material and the archaeological structures was not high enough and it was not possible to reliably identify any of the quested remains.

14.3 FORTE InfoSYS

The third party funded FFG FORTE project InfoSYS is conducted in collaboration with the Austrian Armed Forces and LBI ArchPro partner ZAMG, to establish GIS-based modelling of existing knowledge and real-time integration of high-resolution and precisely located multimodal close-range reconnaissance information. In 2020, data acquisition surveys have been conducted on various test sites involving different sensor systems.

14.4 EU Interreg DTP Living Danube Limes

In July 2020, the EU Interreg DTP project "Living Danube Limes" was kicked off by lead partner Danube University Krems and eighteen project partners from ten countries with the LBI ArchPro being among the three participating Austrian partner institution (Fig. 62).

The project is centred around the Roman Danube Limes as transnational cultural heritage of enormous significance. Spanning the whole Danube region, the project aims at further developing and enhancing the connecting aspects of the Roman heritage sites along the river, thus, fostering a common sense of togetherness in the Danube Region. To achieve this, all partners will collaborate on the exploration and protection of cultural sites as well as the development of green and sustainable tourism and cultural route solutions. The LBI ArchPro will investigate various Roman sites using geophysical prospection methods and contribute to the subsequent creation and implementation of VR reconstructions for pilot sites.

Fig. 62. EU Interreg DTP Living Danube Limes – partner countries.

During the first project period the LBI ArchPro presented an outline of essential criteria for national pilot sites regarding archaeological geophysical prospection and contributed its expertise to steer and support the process of national pilot site selection for all project partners. The aim was to identify which of the pilot sites have a hidden potential for further geophysical prospection and VR applications and to focus on strengthening hitherto underdeveloped sites in the Eastern Danube Region.

The project runs from July 2020 to December 2022.

14.5 Tibetian Tumulus Tradition 2

In the second part of the FWF research project - which is based at the Institute for the Cultural and Intellectual History of Asia (IKGA) and the Institute for Social Anthropology (ISA) at the Austrian Academy of Sciences and carried out in cooperation with the LBI ArchPro - several image-based 3D reconstructions have been made by Martin Gamon from several tumuli, lion statues and a kind of astronomical observatory building in Tibet. The results will be presented in various publications 2021-2023.

Appendix "Media Coverage 2020"

LBI ArchPro

- https://oe1.orf.at/programm/20200115/585739/Begrabene-Wikinger-und-abgenagte-Knochen
- https://oe1.orf.at/programm/20200108/585376/Archaeologie-ohne-Graben
- http://science.apa.at/dossier/digitalhumanities
- https://science.orf.at/stories/3200914/
- Salzburger Nachrichten – print, 03.01.2020 : „Ein altes Symbol und sein magischer Abwehrzauber" (Falkenstein)
- https://www.derstandard.at/story/2000118709987/archaeologische-detailarbeit-zwischen-weyregg-und-stonehenge
- https://www.kleinezeitung.at/steiermark/5841705/Stonehenge-WikingerSiedlungen-Co_Ein-Grazer-als-Detektiv-der
- https://www.noen.at/neunkirchen/neunkirchen-eigener-archaeologe-fuer-stadtgemeinde-neunkirchen-hannes-schiel-stadtarchaeologe-214788352
- https://www.meinbezirk.at/neunkirchen/c-lokales/ploetzlich-stadtarchaeologe-fuer-neunkirchen_a4131552
- https://www.linkedin.com/posts/kaitlin-appleby-34456064_lbg-ludwigboltzmanngesellschaft-lbgcareercenter-activity-6689125576856399873-TKMZ
- https://www.noen.at/mistelbach/ausgrabungen-kleinhadersdorfer-spuren-aus-der-steinzeit-poysdorf-archaeologie-ausgrabungen-222810355
- https://www.abitur-und-studium.de/Blogs/Universitaet-Tuebingen/Barbara-Scholkmann-Preis-foerdert-junge-Archaeologen
- https://www.juraforum.de/wissenschaft/barbara-scholkmann-preis-foerdert-junge-archaeologen-683528
- https://idw-online.de/en/news747445
- https://www.archaeologie-online.de/blog/barbara-scholkmann-preis-2020-vergeben-4632/

Schwarzenbach

- https://www.buckligewelt.at/Tag_der_offenen_Grabung
- https://www.noen.at/wr-neustadt/offene-ausgrabungen-geschichte-zum-angreifen-in-schwarzenbach-schwarzenbach-ausgrabungen-archaeologie-216752374

Kleinhadersdorf

- NÖN/Mistelbach – print, 16.09.2020 : « Einblick in die Steinzeit »
- NÖN/Mistelbach – print, 9.09.2020 : « Spuren aus der Steinzeit »

EU Interreg DTP „Living Danube Limes"

- https://science.apa.at/site/bildung/detail?key=SCI_20200814_SCI39431352655958012
- https://noe.orf.at/stories/3062294/
- https://science.apa.at/rubrik/kultur_und_gesellschaft/Nachbau_von_roemischem_Flussschiff_soll_2022_Donau_befahren/SCI_20200814_SCI39351351655956986
- https://www.noen.at/krems/krems-donau-nachbau-von-roemischem-flussschiff-soll-donau-befahren-krems-archaeologie-geschichte-tourismus-unesco-219223789
- https://www.sn.at/kultur/allgemein/nachbau-von-roemischem-flussschiff-soll-2022-donau-befahren-91493419
- https://www.vienna.at/nachbau-von-roemischem-flussschiff-soll-2022-donau-befahren/6706434
- https://www.vol.at/nachbau-von-roemischem-flussschiff-soll-2022-donau-befahren/6706434
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- https://www.kleinezeitung.at/service/newsticker/5852859/Ab-2022_Nachbau-eines-roemischen-Flussschiffs-soll-Donau-befahren
- https://www.drei.at/de/planet-drei/news/aktuell/story.html?uuid=7e31c984-bebd-4ffe-a269-e037ec61f572
- https://www.puls24.at/news/entertainment/nachbau-von-roemischem-flussschiff-soll-2022-donau-befahren/211598
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Underwater Prospection

- Die Presse –print, 19.2.2020, p.11: „Ein Tauchroboter auf Schatzsuche“
- Kleine Zeitung – print, 19.2.2020, p.14: „Mond- und Attersee bald vermessen“ (https://www.kleinezeitung.at/oesterreich/5770813/Archaeologische-Fundstellen_Tauchroboter-erkundet-Attersee-und)
- Kronen Zeitung – print, 19.2.2020, p.16: „Tauchroboter im Hallenbad getestet“
- Neue Vorarlberger Tageszeitung – print, 19.2.2020, p.12: „Mond- und Attersee bald vermessen“
- Oberösterreichische Nachrichten – print, 19.2.2020, p.27: „Ein Tauchroboter untersucht heuer den Grund des Attersees und des Mondsees“ (https://www.nachrichten.at/oberoesterreich/salzkammergut/ein-tauchroboter-untersucht-heuer-den-grund-des-attersees-und-des-mondsees;art71,3228413)
- Österreich – print, 19.2.2020, p.15: „Tauchroboter erkundet Attersee und Mondsee“
- Bürgermeister Zeitung – print 03/2020, 27.02. 2020, p.22: „Tauchroboter erkundet Attersee und Mondsee“ (http://www.buergermeisterzeitung.info/mehr.php?newsNr=50364&bundesland=NIEDER%C3%96STERREICH&ort=Neunkirchen)
- https://www.meinbezirk.at/neunkirchen/c-lokales/roboter-ging-im-hallenbad-auf-tauchstation_a3933735
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