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

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1 Introduction

1.1 Mission

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

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

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

1.2 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).

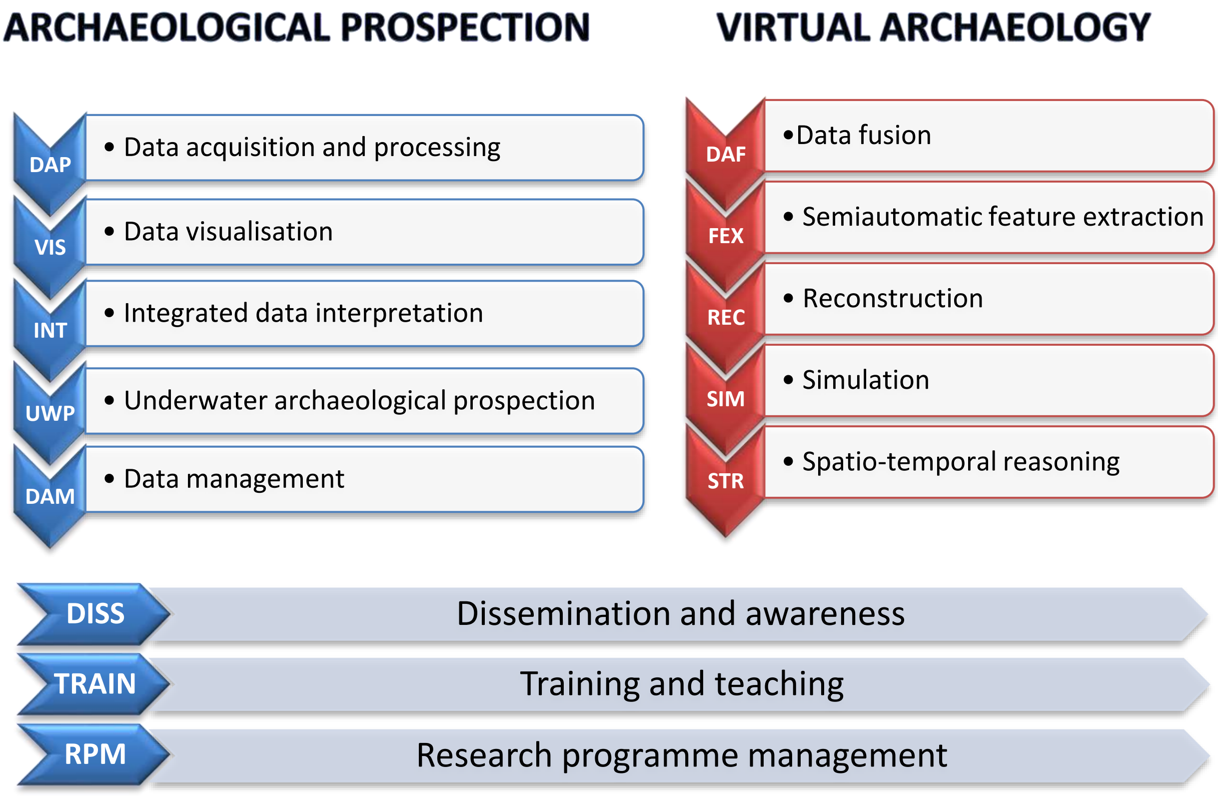


Fig. 4. Research topics within the fields ARCHAEOLOGICAL PROSPECTION and VIRTUAL ARCHAEOLOGY

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 2022 is described according to the defined research topics and lateral programme elements.

2 Data acquisition and processing (DAP)

2.1 Geophysics

Jona

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

Short description of site: Roman villa, medieval church

Datasets: GPR data, excavation data

Keywords: GPR survey, Roman period, Switzerland

Benefits: gaining knew knowledge on a previously identified Roman villa and surrounding structures

In 2022, the investigations around the church of St. Martin Busskirch in Rapperswil-Jona were continued. The remaining areas between the church and Oberseestraße were investigated to determine the dimension of the Roman villa identified in the previous year. For this purpose, about 6 ha were investigated using motorized GPR over three days (Fig. 5).

The evaluation of the data shows a villa of the longitudinal-axial type, except for the absence of the outer wall enclosing the area, which contradicts the classification of this type. Investigations will be continued in 2023.

Fig. 5. Rapperswil - Jona, Busskirch. GPR data of the surveys 2021 and 2022. In the left bottom corner, below the data, the site of the church of St. Martin, excavated in the last century and built in the early Middle Ages on the pars urbana. In the right half of the picture the two southernmost outbuildings. The site is situated on the gravels of the Jona River, which is regulated today.

St. Gallen

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

Short description of site: medieval and modern remains at today's city centre of St. Gallen

Datasets: GPR data, historical maps

Keywords: GPR survey, urban archaeology, Switzerland

Benefits: efficient, non-invasive prospection of archaeological structures as a basis for urban development projects

In cooperation with the Kantonsarchäologie St. Gallen, the market square of St. Gallen was surveyed with a 16 channel - 400 MHz - antenna array from MÅLA over an area of more than 10,000 m^2 during the night of 7th to 8th of March 2022 to provide a basis for the redesign of the square. The medieval town hall and the town fortifications, consisting of a wall and a moat, were located in the area of the measurement. After the moat was filled in at the end of the medieval period, the space was used to erect municipal buildings on it. These, as well as the town hall and the town wall, were then demolished in the 19th century.

The results of the radar survey suggest that the demolition may have proceeded with "Swiss thoroughness", as no clear evidence of the buildings - as depicted in historical maps - has been found (Fig. 6). Another reason for this might be the dense sequence of historical, i.e., no longer in operation, and modern infrastructure lines, which are the most prominent objects in the data. This can provide an alternative approach to the history of modern St. Gallen.

Fig. 6. From left to right: 16 channel MÅLA Mira antenna array in operation in the historic city centre of St. Gallen. Analysis of sewer shafts and installations with ArchProspector 3D, view from south-west. Greyscale-image of GPR data, depth slice 40 - 80 cm (the letter "a" marks a round pavilion).

Carnuntum Forum

Short description of the project: GPR test measurements within research area “Data Acquisition and Processing”
Short description of site: Roman forum in the civil town of Carnuntum
Datasets: multiple sets of GPR data
Keywords: GPR survey, Roman period, test surveys
Benefits: analysis of differing measurement approaches in GPR surveys, workflow improvements

The forum of the civil city of Carnuntum had already been prospected repeatedly with different geophysical methods during the project "ArchPro Carnuntum" 2012 - 2015. In 2022, an area of about 1.25 ha was measured under optimal conditions with two MÅLA Mira 400 MHz 16 channel GPR antenna arrays. The two systems differ both in the channel spacing and in the mounting of the array on the vehicle pushing the antenna array. The possible effects of these differences will be examined on the basis of these data. In total, the area was measured six times (three times with each system): West-East, North-South and Northwest- Southeast (Fig. 7). The aim was to gain a better understanding of potential effects on the dataset that may result from electromagnetic waves hitting the archaeological structures at different directions. The final evaluations are still pending.

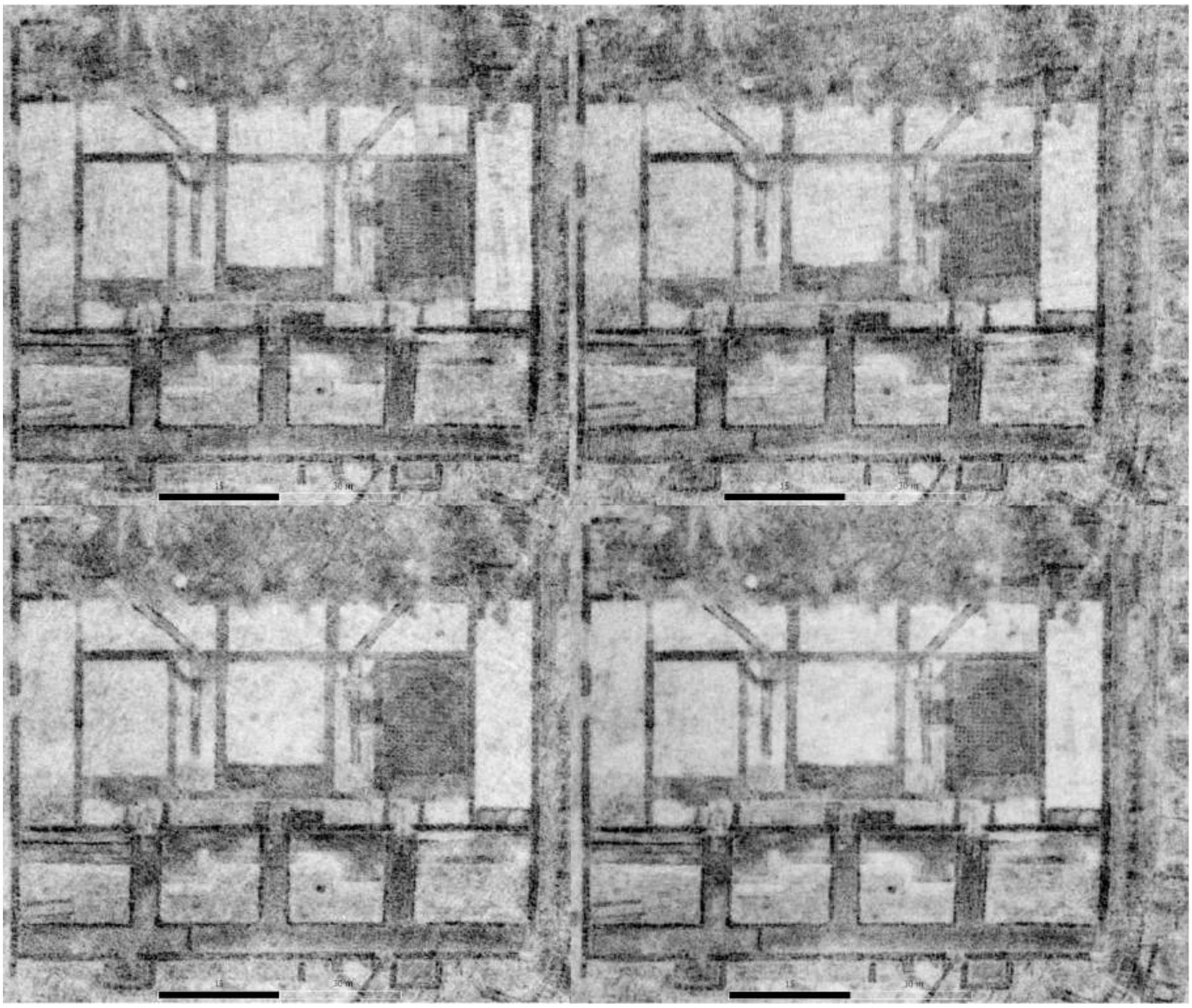


Fig. 7. Southern part of the forum in Carnuntum, GPR survey with a MÅLA Mira 400 MHz 16 channel system. In the most recent measurements, this area could be mapped with more precision than before, as the area was examined in three different directions with each measuring system. The hypocausts in the curia (?) are particularly clearly visible in the combination of all measurements (from top left to bottom right: North-South, West-East, South-West-Northeast, combination of all three directions).

Asparn/Schletz

Short description of the project: Large-scale geophysical prospection of a threatened archaeological landscape

Short description of site: Neolithic settlement and fortification

Datasets: Magnetics (fluxgate, caesium)

Keywords: geomagnetic survey, fluxgate sensors, caesium gradiometer, cultural heritage protection

Benefits: comparison of magnetometry survey methods, digital documentation of a threatened archaeological site

The site of a fortified Linear Pottery settlement was one of the first archaeological landscapes areas to be investigated with large-scale geophysical prospection in Austria in the 1990s. The settlement of Asparn/Schletz is one of the sites associated with a violent cultural upheaval at the end of the Linear Pottery culture as almost seventy skeletons – showing evidence of organised violence - were found in one of the ditches that probably delimited the settlement area. At that time, Caesium sensors were used, mainly in a gradiometer arrangement. In total, about 24 ha were prospected, and the results of these investigations were used, among other things, to optimise the excavation strategy.

In 2022, the southern slope of the settlement facing a stream was re-examined with a motorised 8-channel fluxgate system over two days. The aim was to extend the survey area to the west, to obtain data to assess the impact of natural and agricultural erosion on the archaeological remains and to estimate the difference between data obtained by caesium sensors and fluxgate sensors (Fig. 8). The initial archaeological interpretation has been completed; further analysis is pending.

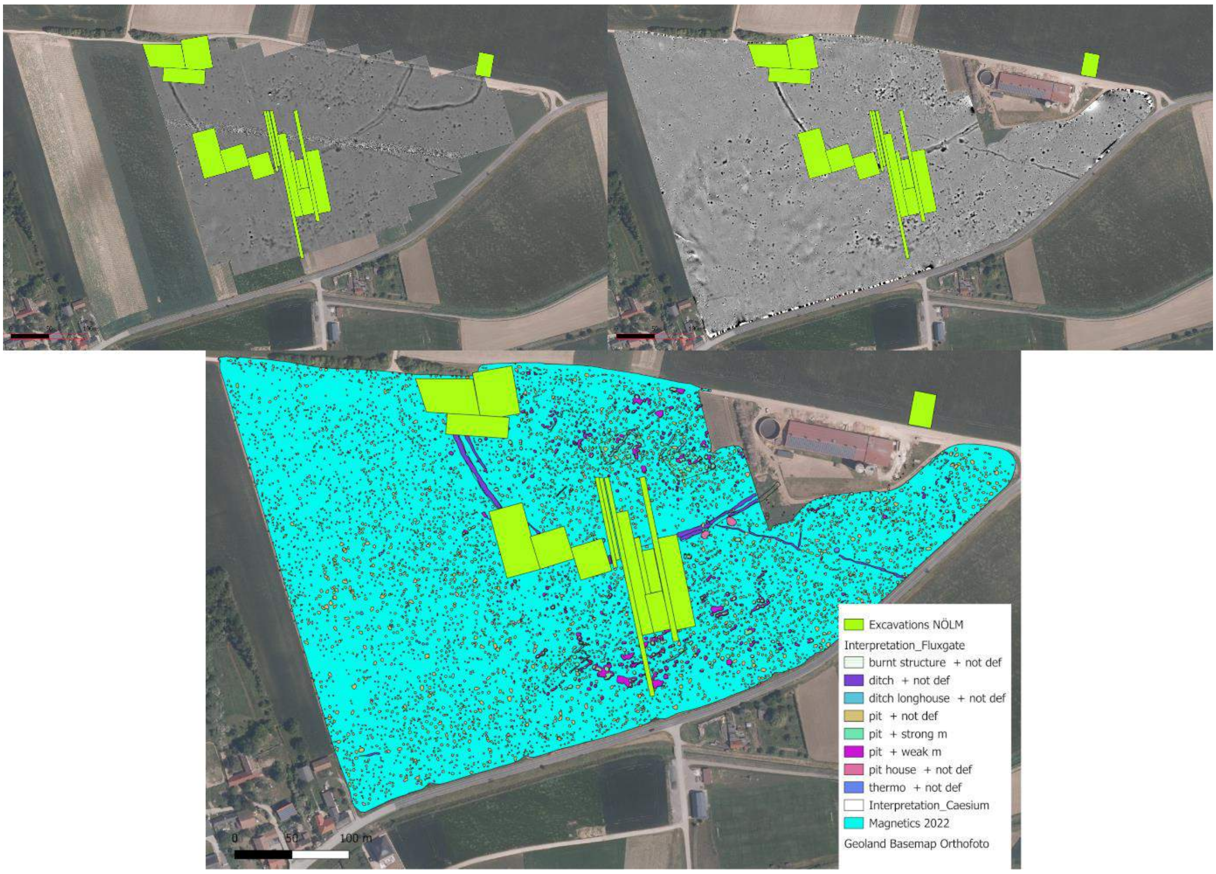


Fig. 8. Shown in yellow are the sections of the excavations of the Lower Austrian Provincial Museum in the years 1983 - 2005. Top left: Magnetogram of the caesium gradiometer surveys in 1997. Top right: Grey-scale image of the survey with fluxgate probes in 2022, dynamics -6nT to 4nT. Below: combined interpretation.

2.2 Extension of ApSoft 2.0

In-house programmer Alois Hinterleitner continued the development of the software package ApSoft working towards the release of version ApSoft 3.0. After completion, this version will be passed on to the full partners of the LBI ArchPro for free use for scientific and operational activities in the non-profit areas in version 3.0 after the closing of the LBI ArchPro.

In 2022, the performance of ApSoft was improved and considerable maintenance work was carried out on the ApSoft code in preparation for the ApSoft 3.0 implementation. The synchronization of MIRA Systems within ApRadar was improved and issues that MIRA Systems is experiencing with channel swapping and time zero calculation were addressed. A new algorithm for creating the boundary of the measurement area was programmed; empty areas (larger than 1 m2) can now be excluded within the measurement area (Fig. 9).

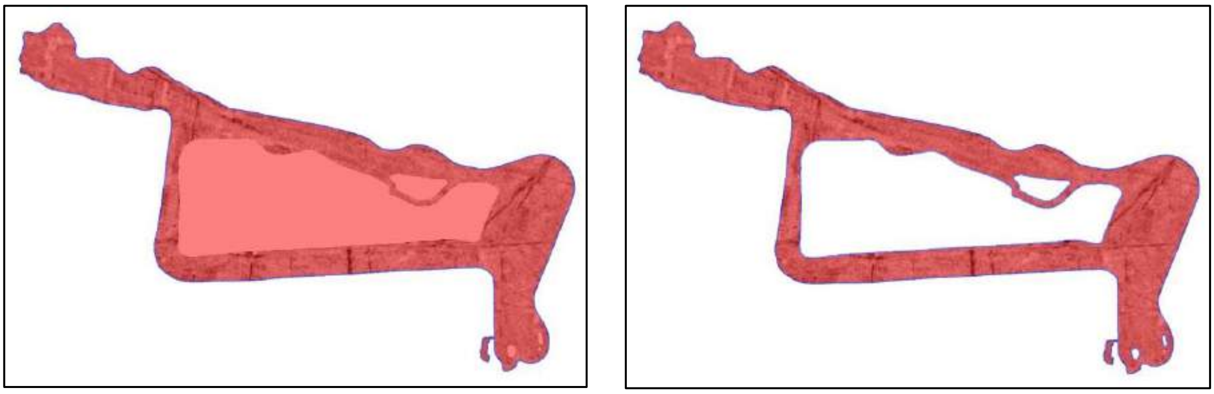


Fig. 9. Left: measurement area with one border including empty areas. Right: empty areas are excluded.

2.3 Image-based modelling

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

In this research area, extensive activities were carried out within the framework of the third-party funded project INDIGO and the remote sensing surveys in Kuelap (Peru), which are presented in chapter 11.

2.4 Terrestrial and airborne laser scanning

During the fieldwork campaign in Kuelap (Peru) various methods including Terrestrial Laserscanning (TLS) and Airborne Laserscanning (ALS), have been applied and combined to record the status of the site in 3D. For a detailed report see chapter 11.2.

3 Data visualisation (VIS)

Modern archaeological prospection provides a variety of heterogeneous data sets. Their joint visualization is of great importance for the recognition of archaeologically relevant information, their relationships and ultimately for a high-quality interpretation. Furthermore, illustrative visualizations including measured data alongside virtual reconstructions support dissemination in an easily understandable way without sacrificing traceability. The visualization software developed at LBI ArchPro aims at optimally supporting these tasks by extending the data overlay concept of GIS to 3D to be able to seamlessly integrate 3D models, point clouds, but also volumetric data like GPR volumes.

3.1 3D data visualisation

Visualization tailored to the respective data set type 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.

For GPR data 3D visualization generally improves the visual depiction of major archaeological 3D structures, in particular the perception of their 3D shapes, over browsing through stacks of individual 2D image in a GIS. Therefore, the innovative 3D visualisation techniques for GPR volumes were continuously improved and extended to supporting the integration of the entire spectrum of data within the scope of prospecting and excavations. This includes 3D point clouds, 3D models from image-based modelling or virtual reconstructions, and 2D images. Flexible domain control mechanisms allow a targeted influence on the way in which certain data sets and data regions contribute to the visualization result. Interpretation models and 3D models from excavations or virtual reconstruction can be included for comparison with prospection data and illustration. Altogether, this leads to unparalleled possibilities for the documentation, analysis, and dissemination of archaeological data as shown in figures 10a,b and 11.

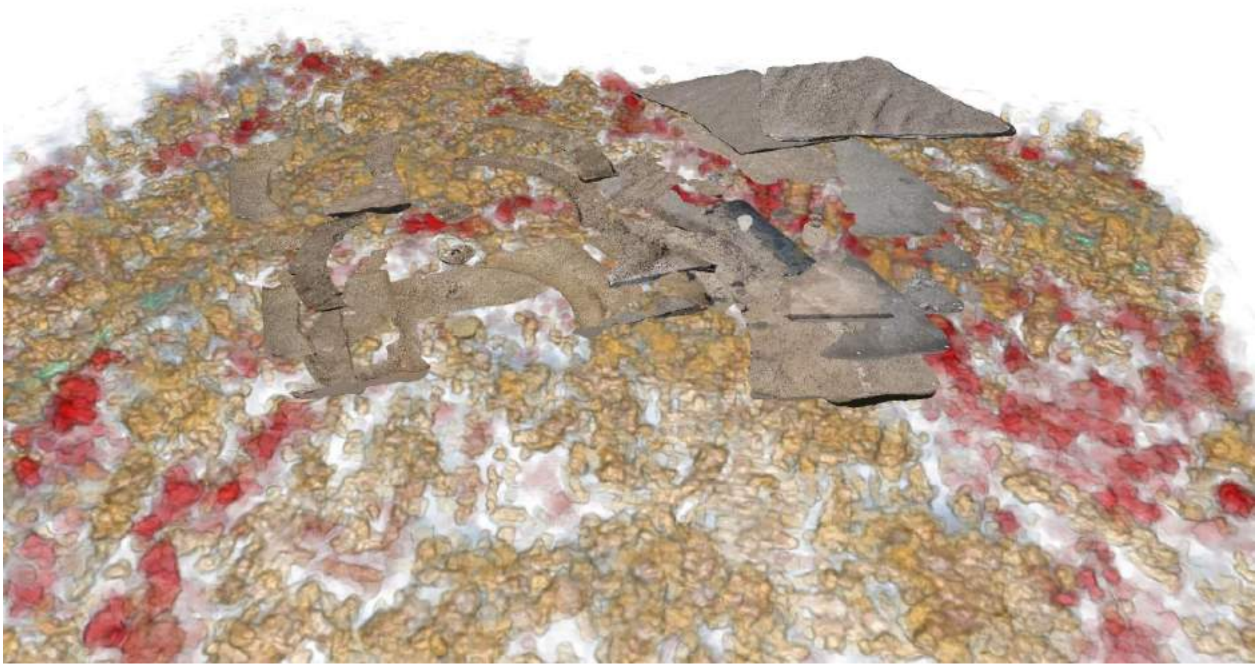


Fig. 10a. Illustration the showing filtered 3D GPR data of the Roman arena in Carnuntum with 3D models of stratigraphic units (SUs) from an excavation using image-based modelling – vertically displaced.

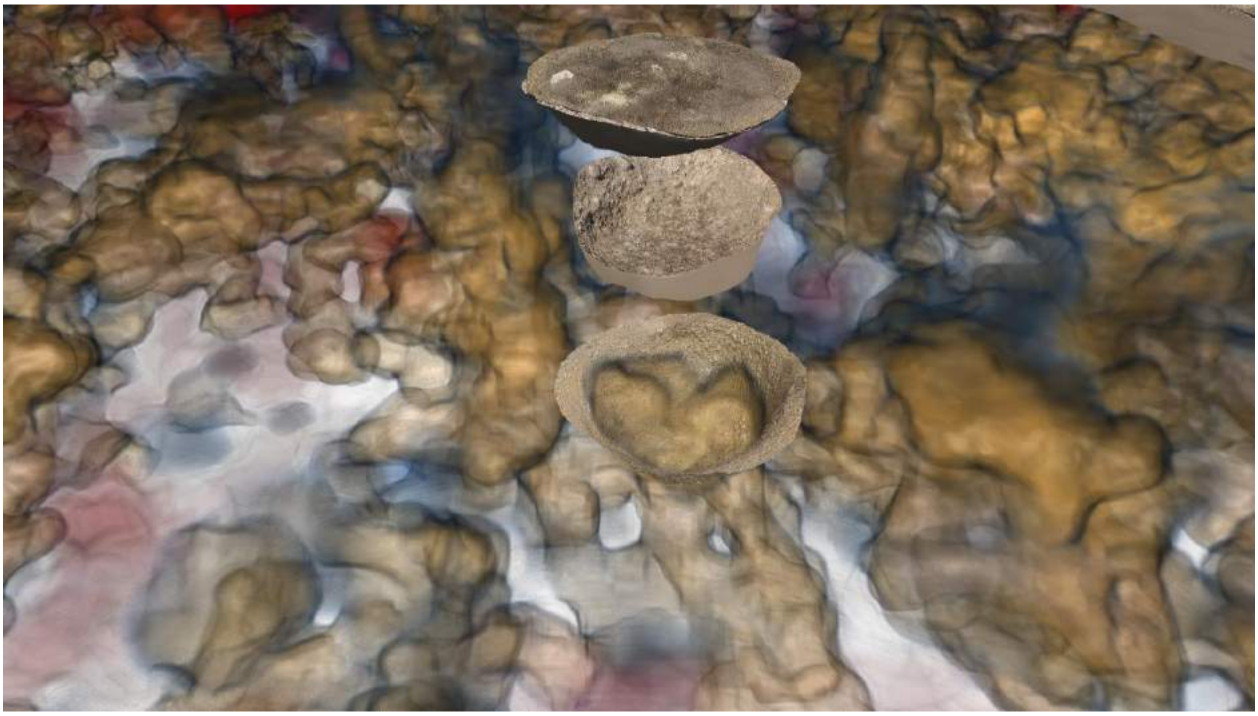


Fig. 10b. Detail view of the same scenario showing good correspondence between a GPR feature of high reflectivity in the center of the arena and a pit filled with stones in the excavation.

3.2 Big data visualisation

In 2022 the existing visualization techniques were developed further with the goal to support datasets exceeding the amount of available graphics card memory. This led to the implementation of a novel memory management framework for the visualization software framework as well as the use of a different data storage format for GPR and point cloud data. Large datasets are stored using "TileDB", a database system organizing large data sets in small spatial portions (tiles). The use of TileDB ensures space efficient storage as well as efficient access to arbitrary dataset sub regions by means of spatial database queries as required by the developed "out-of-core" memory management framework for the visualization. This framework tries to maintain a set of all data potentially contributing to an image rendered from a particular viewpoint. This data subset is much smaller than the complete dataset for practical viewpoint. In case it still does not fit, the management algorithm tries to discard occluded loaded regions to optimally utilize the available memory. As a last resort, rendering continues with incomplete data, which still better that not being able to visualize the dataset at all. Altogether, the supported dataset size is just limited by the amount of external storage. In our experiments we were able to visualize datasets on the order of 100 GB, both from GPR (Fig. 10) and airborne laser scanning (Fig. 12). For the latter, we found that converting point clouds to sparse 3D density volumes improves the visualization over conventional point-based rendering, especially in close-up views, without the need for more costly and error-prone mesh conversion. With the volumetric representation, semi-transparent visualization comes for free, enabling studying, e. g. internal building structures from outside (Fig. 12, top row).

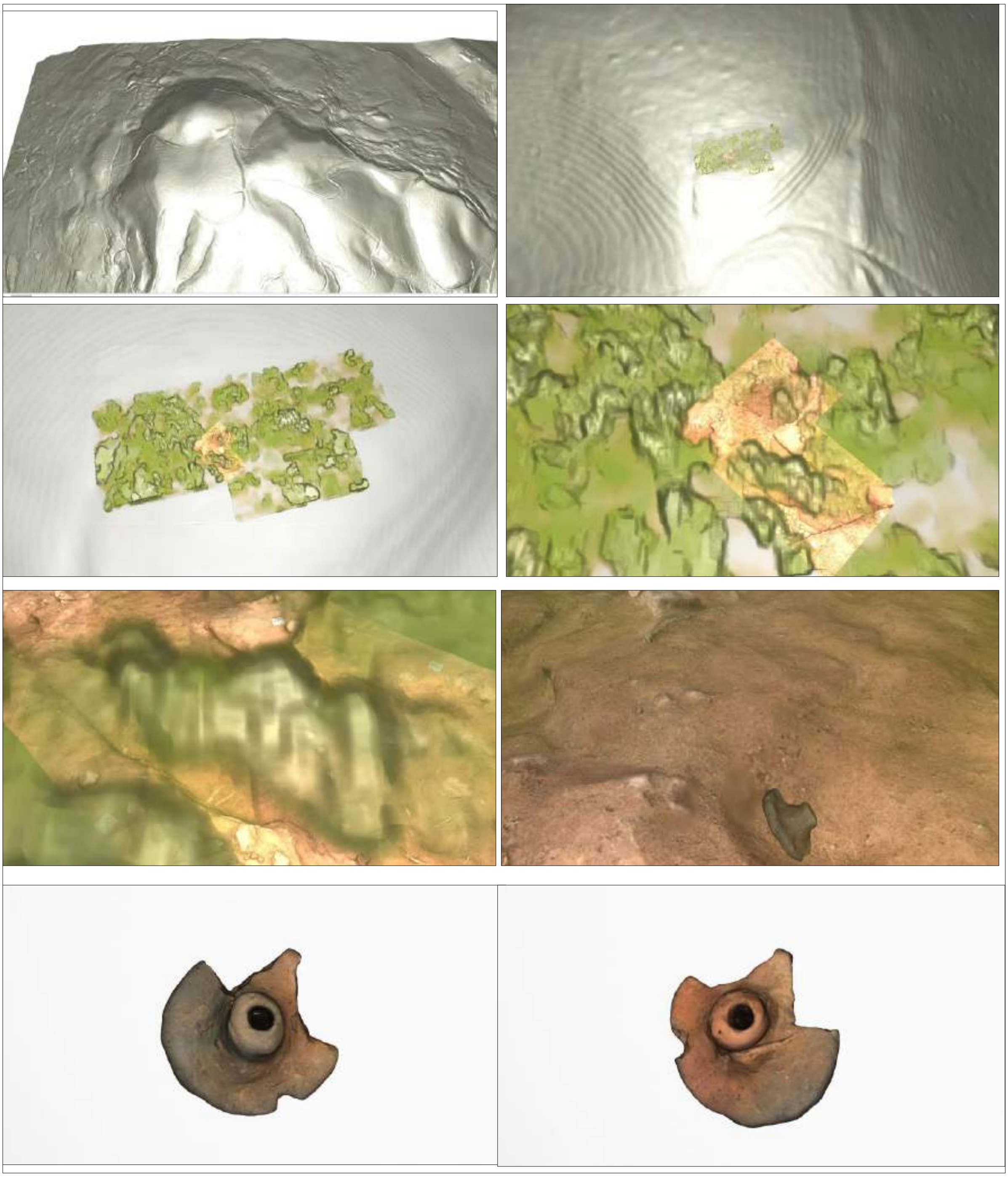


Fig. 11. Big data example – Königsberg, Tieschen/Styria: Integrated visualization sequence starting with a large 3D terrain model with a spatial resolution of approximately 20 cm (top left). Conjoint 3D visualization of semi-transparent terrain model and GPR survey data (top right). GPR visualization integrated with 3D models showing the excavated area (2nd row). Closeup view showing the correspondence between structure detected by GPR survey and a stratigraphic unit (ditch) discovered in the excavation (3rd row, left). Detailed 3D model of a find - wheel of neolithic carriage model re- embedded into coarser 3D model (3rd row, right). Detail views of the wheel. All images are screenshots from a video sequence produced using the animation framework of the software.

Fig. 12. Big data visualizations: High-resolution 3D point cloud from the Lipizzaner stud Piber, Styria recorded using a 3D laser scanner mounted on a drone. For semi-transparent visualization the point cloud was converted into a 3D density volume representation (top). High resolution point cloud visualizations from ALS dataset from Kuelap, Peru including colour information (center and bottom).

3.3 Georeferenced scenes and new representation types

Alongside with big datasets and development of import/export capabilities support for georeferenced scenes was added. This enables efficient import of georeferenced datasets, data exchanged with GIS, e. g. export of interpretation polygons and models.

Moreover, support for data represented by lines was added, to be able to visualize, e. g. infrastructure like buried cables and sewer systems (Fig. 13).

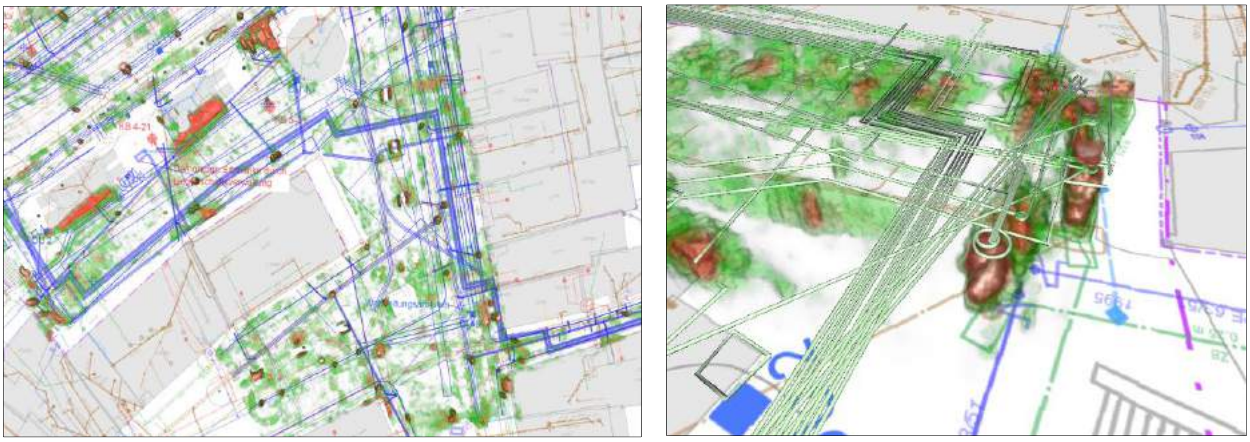


Fig. 13. Infrastructure visualization based on map and 3D line set integrated with GPR visualization to simplify distinguishing between modern infrastructure and potential archaeological features. 3D line set can be visualized as such (left) or as tubular geometry automatically constructed from the line representation (right). In both cases, a connection between some of the high radar reflectivity features and sewer shafts can be made.

4 Integrated data interpretation (INT)

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

4.1 Lipizzanergestüt Piber

Short description of the project: digitalization project at the Lipizzaner Stud Piber with the Spanish Riding School

Short description of site: 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

From 2020 to 2022 the LBI ArchPro conducted large-scale geophysical surveys at the Federal Stud Piber. Comprehensive processing, integrative analysis, and interpretation of the acquired data sets was carried out in 2021 and 2022 and included in the final report of the "Piber Digital" project with the Spanish Riding School in 2022. The aim of the geomagnetic and ground penetrating radar surveys was to investigate all areas of the Lipizzaner Stud Piber, which from a topographical point of view and the vegetation allow prospecting, to obtain a better overview of the prehistoric and historical use of the area. The main findings are presented in the following section.

Motorized magnetometry – results and interpretation

Motorized magnetometry surveys were completed in 2022 with the closing of the gap between the 2020 and 2021 areas at Langsackbach and the investigation of the area between Rosenthal and Piber; in total almost 45 ha were magnetically prospected. Thus, a magnetic prospecting data set is available that covers a total area of about 78 ha (Fig. 14). All areas accessible until autumn 2022 were covered.

Modern infrastructure fixtures are found in varying degrees of dynamics in all surveyed areas. Large magnetic dipoles scattering across the surface could be related to mining development in the area, indicating boreholes or shafts. In some areas, the number of magnetic dipoles severely limits the meaningfulness of the results. This is especially true in the areas immediately around the Lipizzaner stud farm. Here, the use as pasture for the horses and the loss of horseshoes and horseshoe nails and the creation of paddocks that can be assumed in the process seem to be evident.

Filtering of datasets makes the interpretation of archaeological features possible, nevertheless. For example, rectangular structures stand out in the surveyed area on parcel 76/78, which may either represent settlement structures or may be related to horse breeding (Fig. 15). On the western edge of this area, an approximately 10 m by 5 m house floor plan or former stable or barn could be apparent.

The existing fences of the paddocks are characterized by chains of black and white prominent dipole anomalies. The different density of the smaller dipole anomalies gives a clear indication of the different long-term use of the plots as paddocks or grasslands. The different intensity of fertilization can also be seen in the anomaly density, since smaller iron particles are also always brought to the fields with the manure.

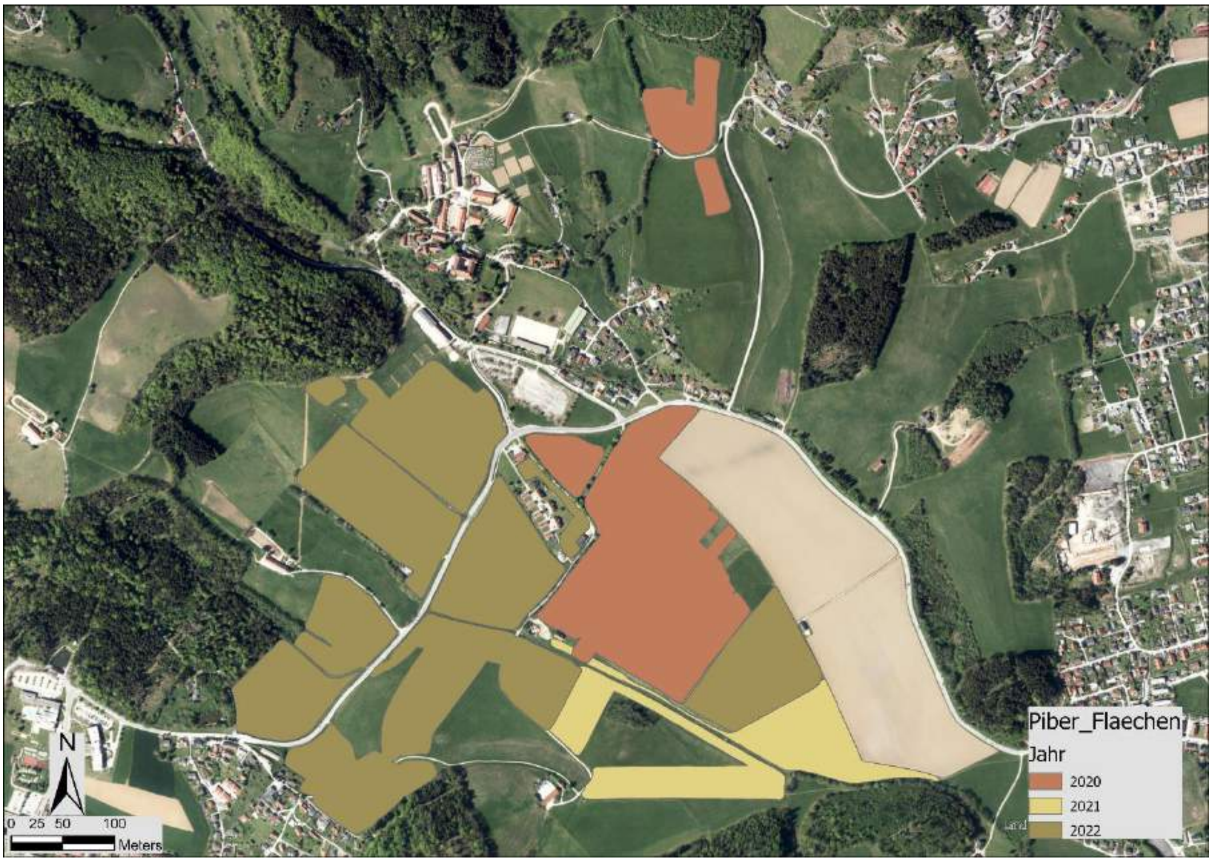


Fig. 14. Overview of geomagnetic survey areas in Piber 2020-2022.

Fig. 15. Piber, parcel 78: left geomagnetic data, right data interpretation.

In the southwestern measurement area, two areas with concentrations of dipoles stand out (Fig. 16). The geological conditions do not seem to offer any explanation for this phenomenon; the regular arrangements of individual anomalies in this area indicate that these are planned structures and not recent filling of terrain depressions with building rubble. A connection with historic mining has not yet been confirmed. Slightly northeast of these exceptionally large anomaly areas is another small anomaly area that suggests a filled-in extraction pit or terrain depression.

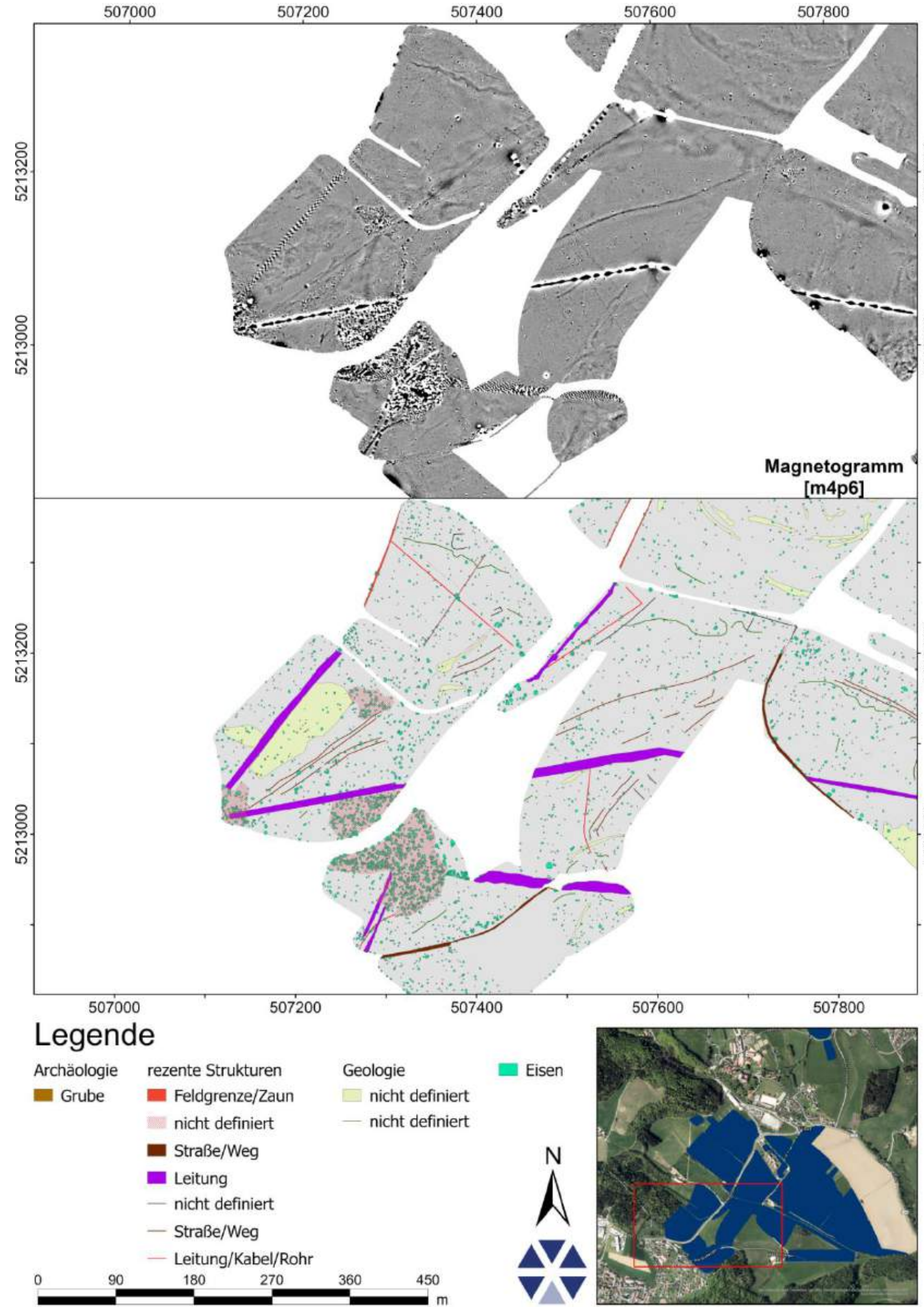


Fig. 16. Piber, south-west survey area.

In both areas of the parcels 360, 375/1, 376 and 355/1, pits and linear structures perhaps indicate a settlement area or working area, which may be related to the historic mining for coal documented from 1761 to 1935 (Fig. 17). A strong disturbance is visible at the north-western edge of the survey area, suggesting the refilling of a collapse shaft of the mining area. A massive geologic anomaly running northwest to southeast through the northeast survey area indicates the geologic boundary of the partially mined coal bed. Overlay with the historic mining map shows good agreement with respect to the interpretation made that the observed structures are related to historically documented mining (Fig. 18).

Fig. 17. Piber, parcels 360, 375/1, 376 and 355/1 south of Knobelbergstraße. Left: geomagnetic data, right: data interpretation.

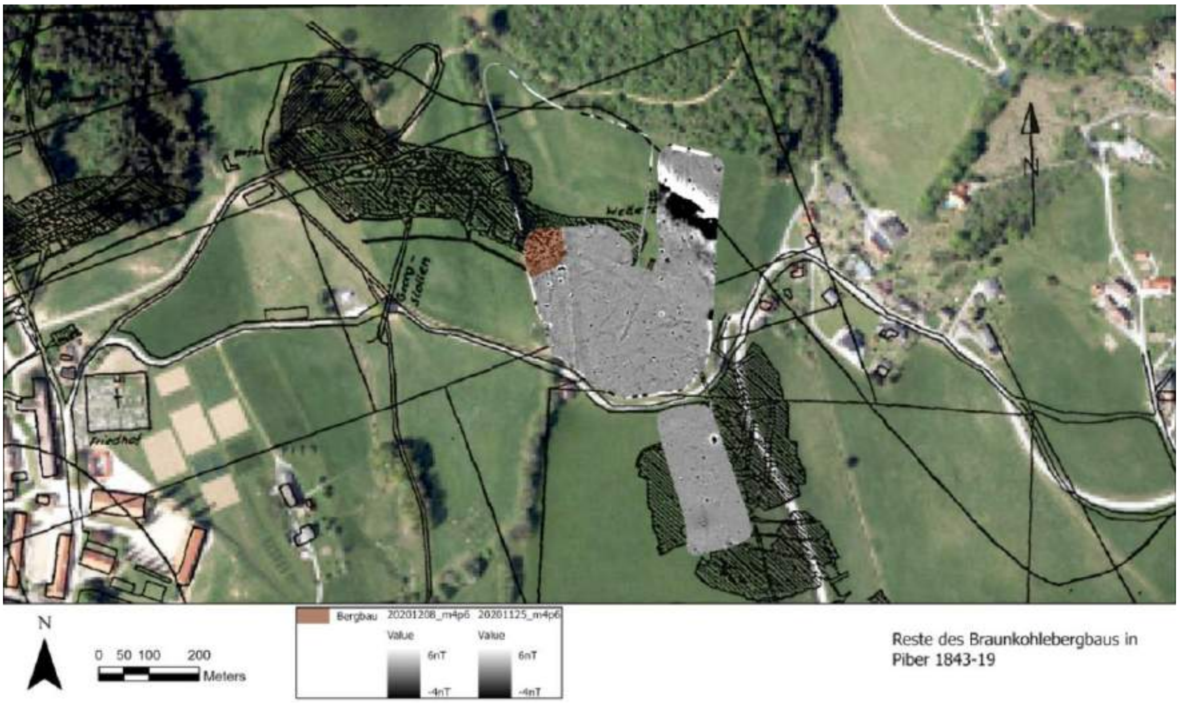


Fig. 18. Overlay of the geomagnetic data with the historic mining map of Piber.

Motorized GPR – surveys and results

After the ground penetrating radar measurements around the church of St. Andrew in 2020 did not reveal any evidence of a Roman building, the other measurable areas in the central area of the Federal stud were investigated.

In the southern area to the east, adjacent to the visitor parking lot, massive wall structures become apparent from 60 cm, which are associated with an elongated building with several rooms (Fig. 19). This building lies parallel with its broadside to the stream running north of the survey area. Based on the depth, the massive design of the walls as well as the room division, it can be assumed that these are Roman building structures. Towards the southeast the building has a porticus and at the southeast corner it probably had a roughly square room with a floor heating system. This hypocaust is another clear indication of a Roman date for the building. The floor area of the building can be assumed to be at least 600 m2 and is most likely to be characterized as a residential building, also due to the heated room. To the south of the building, two other square buildings can be located, which were largely constructed as wooden buildings.

Due to its dimensions and design, the Roman building is most likely to be associated with a Roman Villa Rustica, although it can be assumed that adjacent buildings may have been located in the area of the modern settlement north of the stream. However, since this is on private land, a survey of those areas of interest has not been planned.

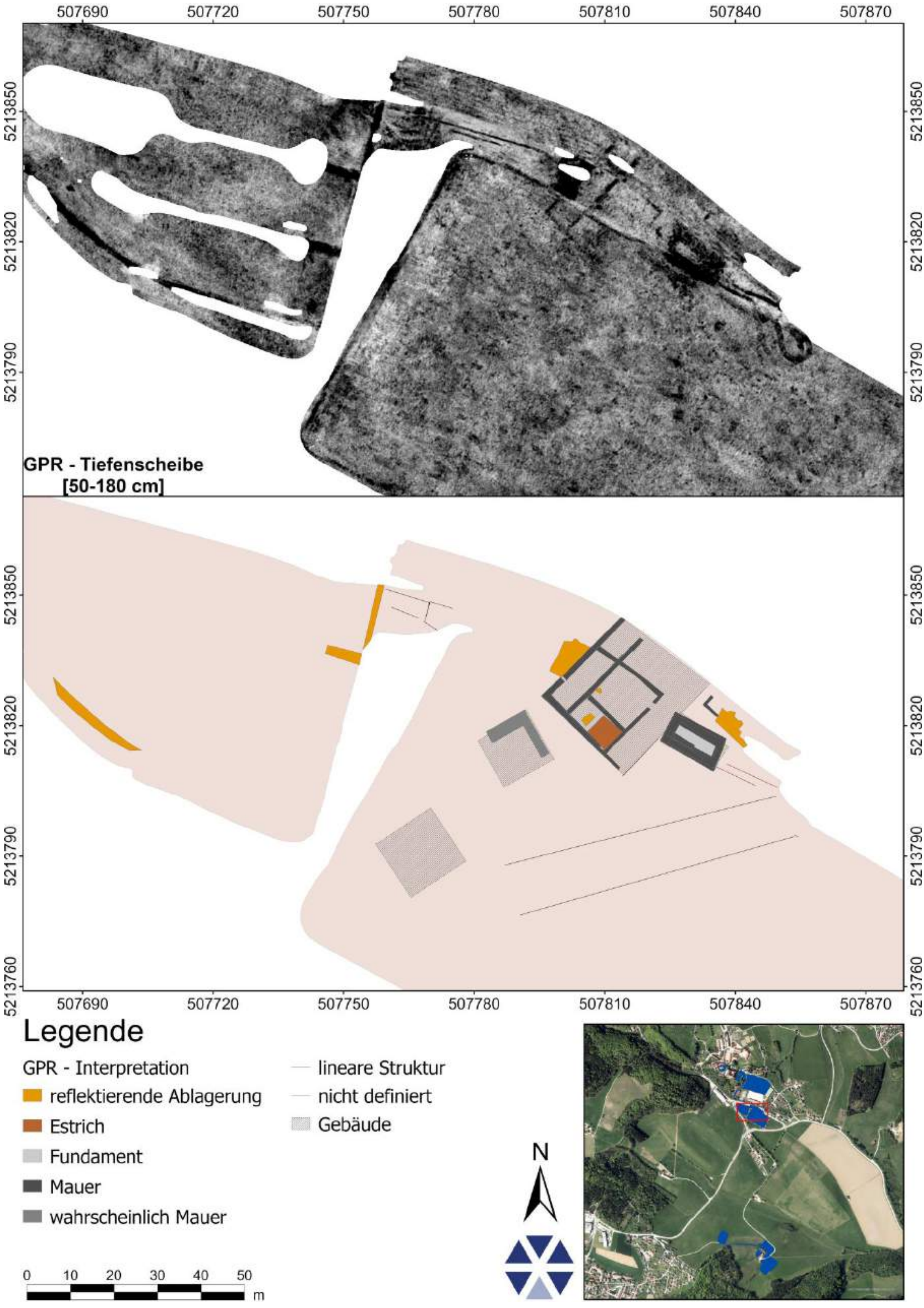


Fig. 19. GPR data showing structures of a possible Roman building at the Federal Stud Piber.

Evaluation of historical documents, illustrations and maps

For a better understanding and more precise evaluation of the archaeological survey data, a comparison was also made with historical maps and other historical sources. Historical illustrations by Georg Mathias Vischer from the early 17th century as well as the *Franziszeische Kataster* (1823) and the *Josephinische Landesaufnahme* (1784/1785) were consulted and analyzed together with the other data. This allows not only to better understand historical developments of the landscape, but also to relate specifically documented structures from the prospection data to certain historical buildings and a certain period of use.

The Rheinthaler Hof, known from historical maps, could be located by high-resolution UAV surveys (RiCOPTER) in the today's forest area between the farms Wilhelm and Kampl (Fig. 21). Well preserved ruins of the main building and less preserved structures of other outbuildings are clearly visible in the high-resolution terrain data.

The localization of Grub Castle could also be clearly determined by means of the RiCOPTER UAV surveys and historical illustrations with reference to the GPR measurements (Fig. 20). The former Grub Castle is located in the area of the later Grubhof, today's Aussenhof Grub of the Lipizzaner stud Piber. The elongated outbuildings localized by the GPR measurements, which may be interpreted as stables or granaries of the castle, are clearly recognizable in their position in relation to the castle, especially with regard to the last phase in the historical picture. The south-eastern front of the castle lies below the present-day stable building of the stud and may have had a courtyard enclosed with masonry. To the northeast of the main building, a defensive wall can be seen in the illustration, and in the rear area, another roof area approximately parallel to the main building.

Based on both historical illustrations and the GPR data, it can be assumed that the castle Grub was at least temporarily surrounded by a fortification ditch or a moat. The strongly absorbing deposits most likely indicate a water ditch.

Fig. 20. GPR data and historical illustrations of castle Grub provide new information on the castle's layout.

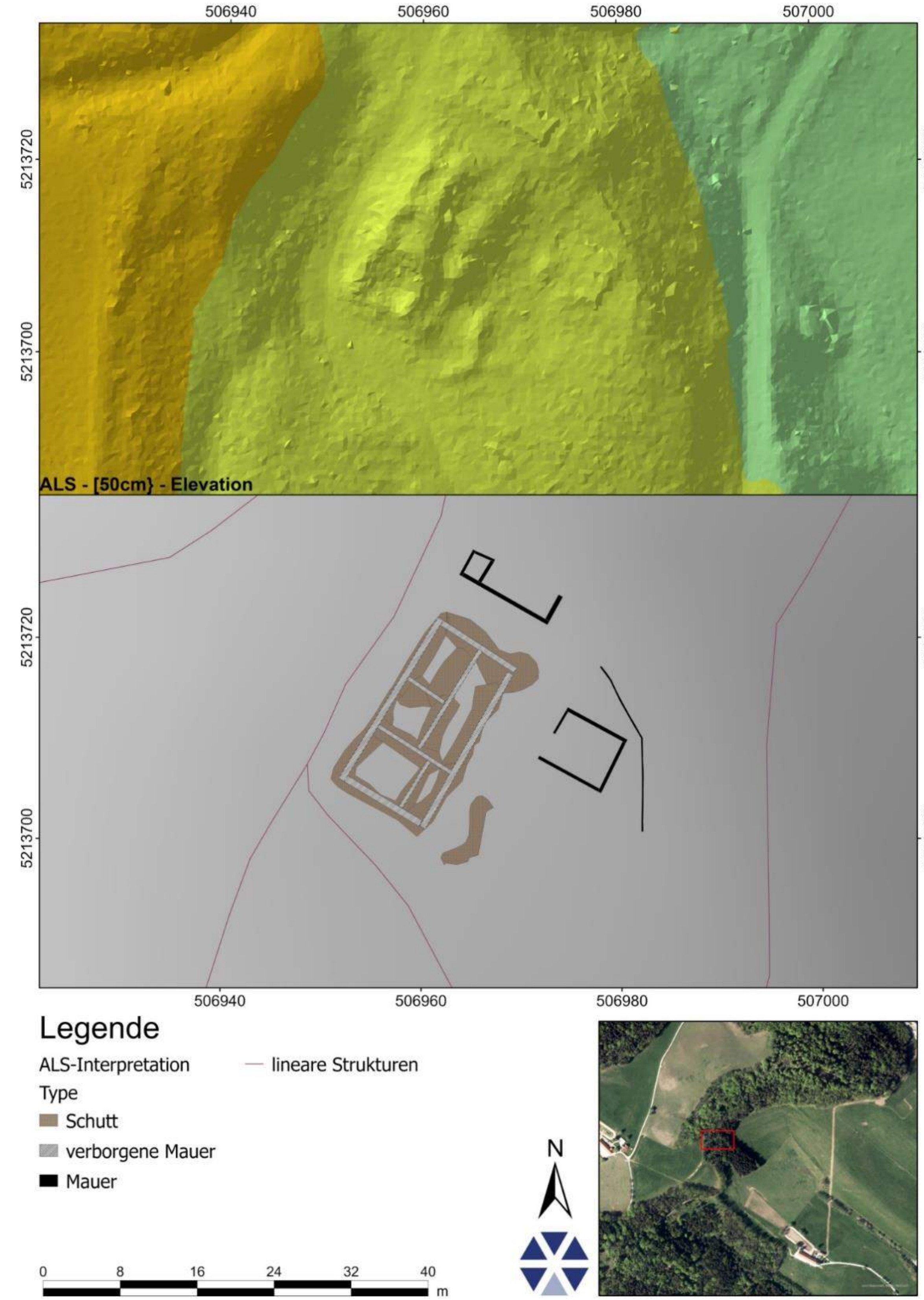


Fig. 21. UAV ALS data of the Rheinthaler Hof.

Based on the available historical maps, the high-resolution terrain model of the landscape around Piber was used for georeferencing the base maps and integrate them into the overall GIS-project (Fig. 22).

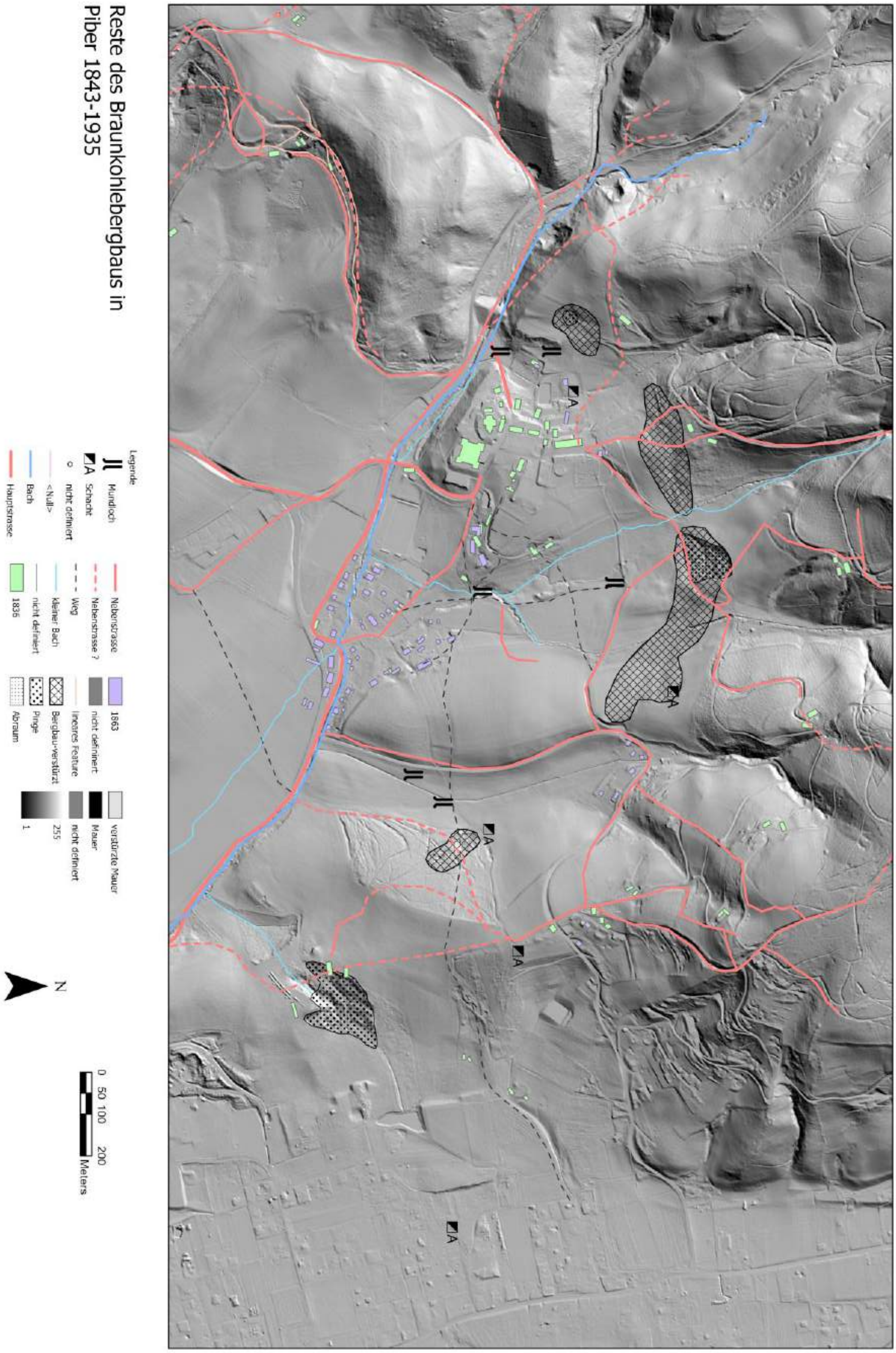


Fig. 22. The integrated interpretation of ALS datasets and historical maps support the reconstruction of brown coal mining in Piber.

4.2 Langes Thal

Short description of the project: Detection and investigation of two deserted medieval villages and a medieval motte-and-bailey castle

Short description of site: Two sites – Dernberg and Scharwarn – situated on highly eroded terrain at brooks

Datasets: GPR; Magnetics; UAV-ALS; historical sources

Keywords: GPR, 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.

In 2022, two sites were in the focus. On the one hand, an abandoned village south-west of the modern settlement Enzersdorf im Thale - "Scharwarn" – 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 respectively the GPR data yielded rather good results which allowed to detect the location and extent of both villages (Fig. 23), although they seem to be highly eroded, showing the urgency of measures to document the sites. In the case of Scharwarn, some old field systems were detected in the GPR data and 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. Furthermore, in 2022 the integrated interpretation of the Dernberg data was published in an international peer reviewed article as well as in another article that has been submitted for publication.

- Filzwieser, Roland; Ruß, David; Kucera, Matthias; Doneus, Michael; Hasenhündl, Gerhard; Verhoeven, Geert Julien Joanna et al. (2022): History and Archaeology in Discourse on the Dernberg–Reconstructing the Historical Landscape of a Medieval Motte-and-Bailey Castle and Deserted Village. In: Heritage 5 (3), S. 2123–2141. DOI: 10.3390/heritage5030111.

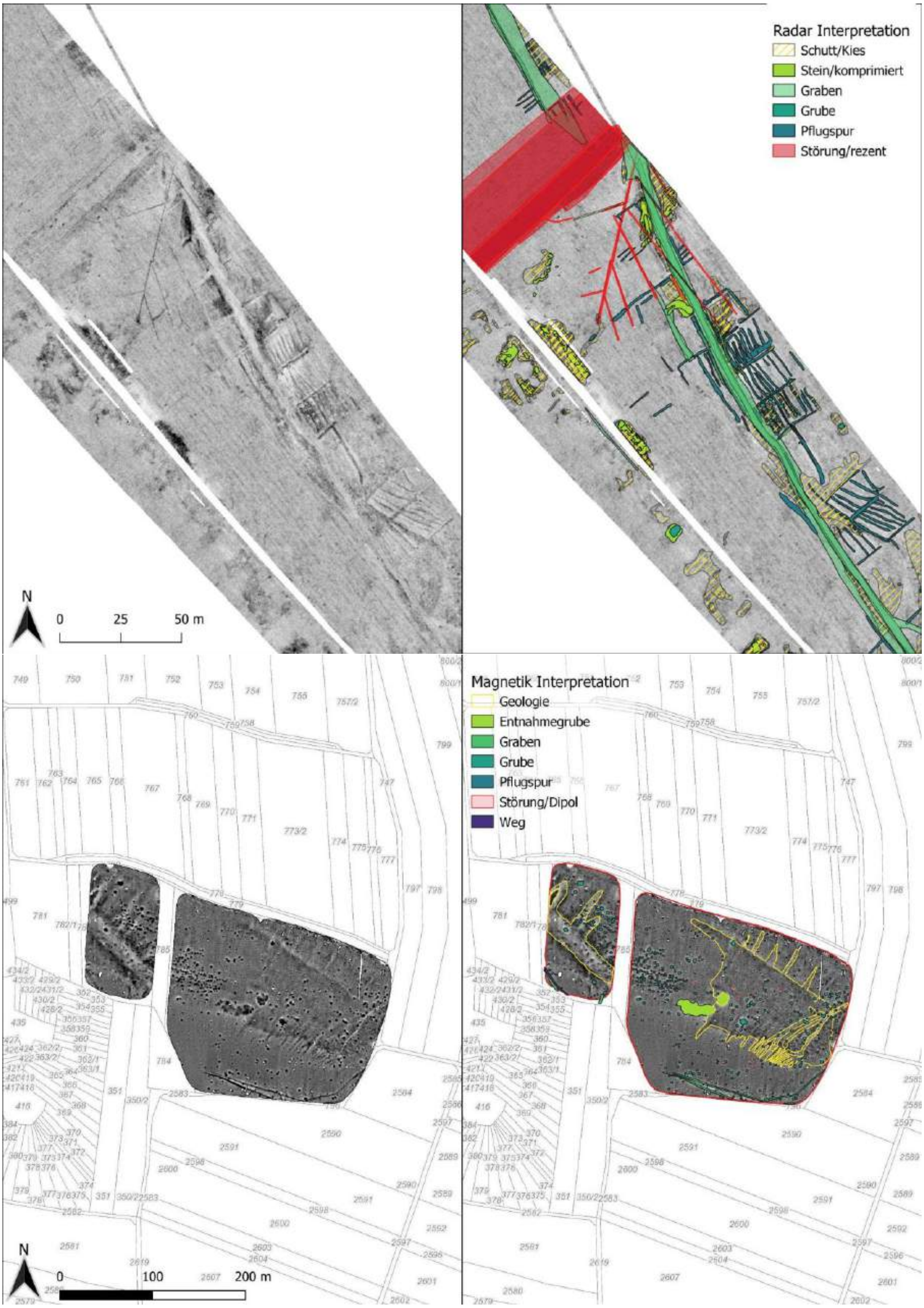


Fig. 23. Above: GPR data of Scharwarn. A ditch or later channel cuts the former field system of the village, which must have been situated further southwest. Below: Magnetic data of the Dernberg with its associated deserted bailey suspected in the eastern field, of which mainly an eroded early modern field system is clearly visible.

5 Data Management (DAM)

After the closing of the Langenzersdorf site in June 2022 and relocating IT infrastructure, ArchPro data and IT workplaces are distributed over 4 major locations (Fig. 24): the Vienna Institute for Archaeological Science (VIAS) located at the Institute for Prehistory and Historical Archaeology of Vienna University, Tieschen, Styria (TI), ZAMG, and the centralized server room of Vienna University's IT department (ZID). Without a dedicated and trained system administrator, several staff scientists do their best to manage the computing resources, at cost of their own research time.

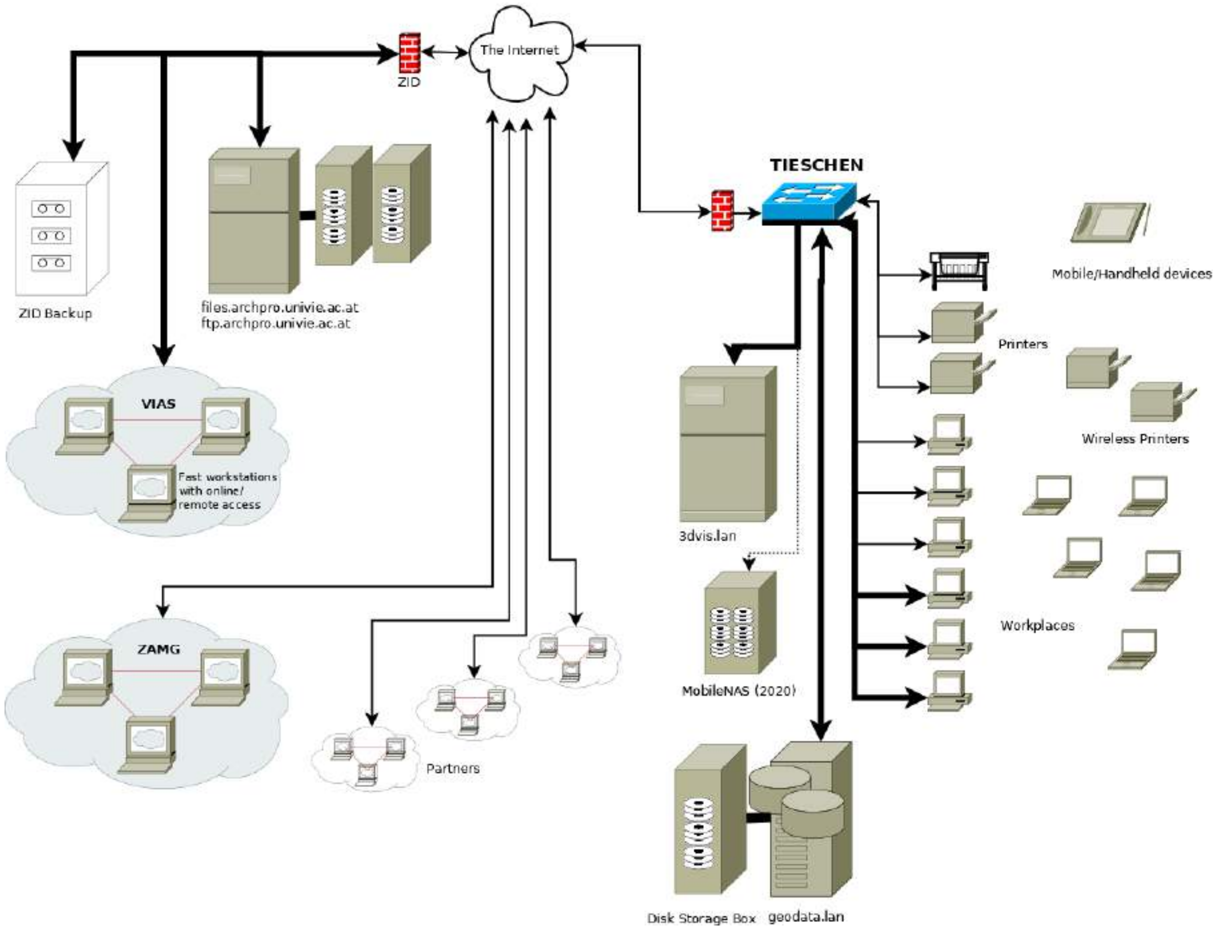


Fig. 24. Distribution of ArchPro data over 4 major locations.

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

Harddisks from the RAID storage have to be replaced as they fail. RAID volumes consisting of small-capacity disks (<=4TB) are dissolved and replaced by volumes with larger disks when replacement disks are not present.

The network infrastructure at the new site, the research center in Tieschen/Styria, was planned and implemented from the ground up. The 10Gbit/s switch relocated from Langenzersdorf allows very fast LAN connections in the office and lecture rooms. In addition, WLAN coverage was ensured throughout the entire building. Servers and PCs now located in Tieschen can be transparently accessed from the other sites using the VPN solution established in 2020, which also allows access to the institute's IT infrastructure from remote locations in field work or home office. The network infrastructure at Tieschen/Styria was extended based on user feedback resulting in good WLAN coverage even in the basement where finds are washed and documented. Printers and plotters transferred from Langenzersdorf were also integrated.

The reasons to move the servers to Tieschen include data security considerations – data is physically stored at two different locations - as well as the upcoming fiber optic internet connection, which renders the spatial distance between the servers and the users irrelevant. It was installed shortly before the turn of the year. The chosen tariff allows 500 Mbit/s transfers. Upgrading to 2Gbit/s is only a question of running costs. Up to now the 500 Mbit/s have proven to be adequate even for the transfer of larger datasets like GPR volumes and 3D point clouds. The nightly backup routine (rsync) which should send new data to the Arsenal server where they are mirrored in a new second disk box before being backed up by the ZID tape archive can only be re-established in Q1/2023.

Further services running on the Tieschen servers are license servers for some commercial software titles for which LBI ArchPro has floating network licenses. In addition, gitea is used to host a centralized repository for software development.

The intranet cloud solution based on NextCloud established in 2021 is increasingly being used for measurement datasets and documents. Using a user-defined sub-set of the whole cloud storage is mirrored on the local hard disk of the user's PC. The Cloud client software automatically keeps it up to date with the server storage and transfers changes and additions performed by the user to the server, whenever an internet connection is available. Such a solution is generally ideally suited for the data flow patterns occurring in daily routine, e. g. the fact that most of the data is static like measurements and, that data are typically only modified by one person at a time. The data copies on local user hard disks prevent data loss. There is no need to manually make backups as long as the PCs is regularly connected to the VPN and thereby able to synchronize with the cloud. Conversely, user do not rely on an internet connection in field work. They just need to make sure that data they potentially need is part of the locally mirrored cloud storage subset.

The second server (named geodata.lan) has been moved from Langenzersdorf to Tieschen. With the VPN setup, this acts as centralized network file storage for everyday work done at Vienna University and Tieschen via remote desktop connections.

The two powerful PC workstations have been transferred from Langenzersdorf to Vienna University for VUX and TLS data processing. These can be reached via VPN (Remote Desktop) so that members can access them also from home office. The 10GB/s connection to the file server (geodata.lan) was however lost in the transfer.

Most staff formerly working in Langenzersdorf are now working in the LBI ArchPro's rooms at Vienna University. Computers and equipment were moved there, and some obsolete hardware was sorted out in the process. A few more modern PCs were refurbished and partially upgraded with faster components (SSD, GPUs). However, most PCs will not be able to be upgraded to Windows 11 due to Microsoft's high system requirements, i.e., they will be obsolete in October 2025.

To enable rapid and uncomplicated transmission of prospecting data and data collected during excavations, a mobile IT infrastructure setup ("MobileNAS") was developed. This consists of a mobile router for broadband Internet access, a network switch to connect PCs, a long-range access point for WLAN coverage at excavation sites, a NAS with 20 TB storage capacity for on-site processing and archiving of data, and an uninterruptible power supply, all housed in a mobile server rack. Using this rack, an efficient and secure IT infrastructure can be set up quickly at practically any location, from which all resources such as servers and workstations can be transparently accessed and used. It saw its first service in Tieschen in summer of 2021. The system was further improved by changing the UPS to an "online" version, which can cope with the voltage and frequency fluctuations of the generators used in field work. It provides the clean 230V 50 Hz sine waveform needed for off-grid operation of sensitive electronic equipment like the NAS.

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.

6 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 archaeological tasks, most notably visualization and interpretation. Both, visualization an interpretation of GPR data require or at least benefit from (semi-) automated processing. For larger sites or landscapes a higher degree of automation is inevitable to accommodate the vast amounts of data at all.

6.1 Filtering and segmentation of large datasets

GPR can capture subsurface information at geometrical resolution on the order of centimetres. The resulting images appear noisy by depicting small features like individual stones. This is often suboptimal for visualisations aiming at the depiction of larger archaeologically relevant structures as well as their automated extraction.

Therefore, filters suppressing small structures beyond the scope of interest and noise were developed. Such filters can emphasize larger structures of archaeological interest like foundation walls, pits or postholes. In 2022, the filtering algorithms up to now only feasible for datasets fitting on modern GPU graphics were adapted to enable offline processing of huge datasets via command line tools. This allows performing time-consuming filtering as part of data processing, right after dataset reconstruction from raw measurements.

In the upcoming year big data processing will be available through the visualization GUI for local computations within huge datasets, e.g., computation of a filter or execution of a segmentation algorithm to extract features of building scale. At the moment this is only possible for smaller datasets (Fig. 25).

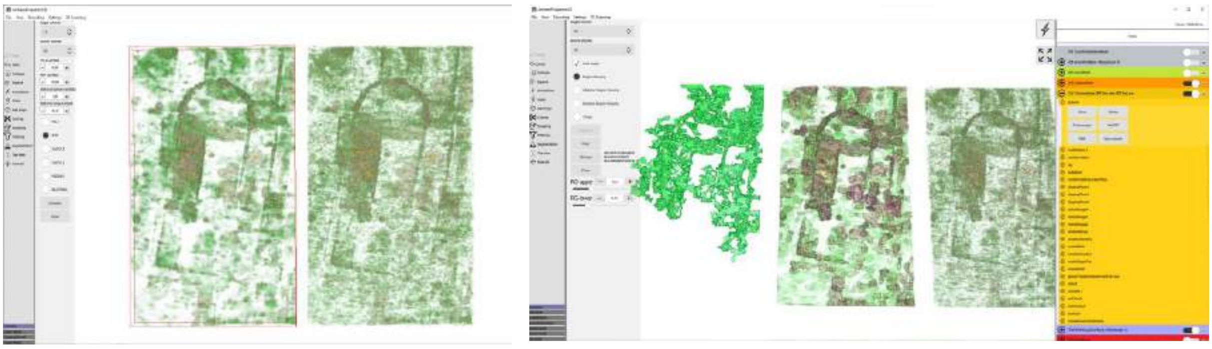


Fig. 25. Side by side visualization of filtered/unfiltered versions of the Corvey GPR dataset containing the remains of a church(left) and a semiautomatic segmentation obtained using the integrated segmentation tools.

6.2 Interactive Interpretation

Segmentation of archaeological structures in GPR data is a comparatively laborious process even with interactive computer-aided segmentation tools. In practice, explicit and true to the data evidence is not unconditionally needed. In an interpretative process aiming at the reconstruction of the original state at the time of use, it might not even be desired to accurately the state of an archaeological structure after destruction or decay.

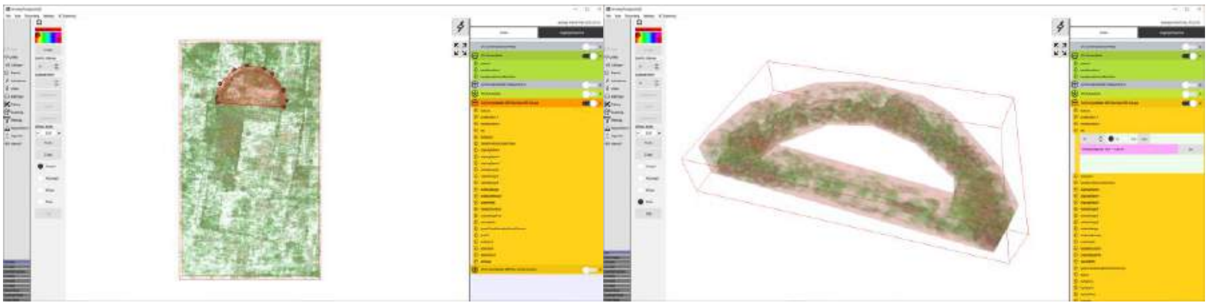


Fig. 26. Initial interactive interpretation tool based on pointwise extrusion polygon specification using a mouse. Interpretations can be refined by specifying additional polygons and applying Boolean operations UNION, INTERSECTION, and DIFFERENCE. The resulting interpretation models can be used to restrict the dataset visualization domain (right) or locally change visualization style for better structure depiction.

Therefore, the visualization was complemented with the 3D equivalent of the GIS based interpretation approach: Tools enabling drawing polygons on top of 3D visualizations of GPR data. Based on the 2021 version of this tool and user feedback, this tool was continuously improved in 2022. The initial approach to define interpretation polygon extruded to 3D using explicit clicks was found too cumbersome for practical use (Fig. 26. Therefore, the tool was developed further to support a more intuitive way of drawing interpretation outlines on top of 3D visualization based on observation of human experts performing GPR interpretation using a tracing paper glued on a tablet PC and coloured pencils as shown in Figure 27.

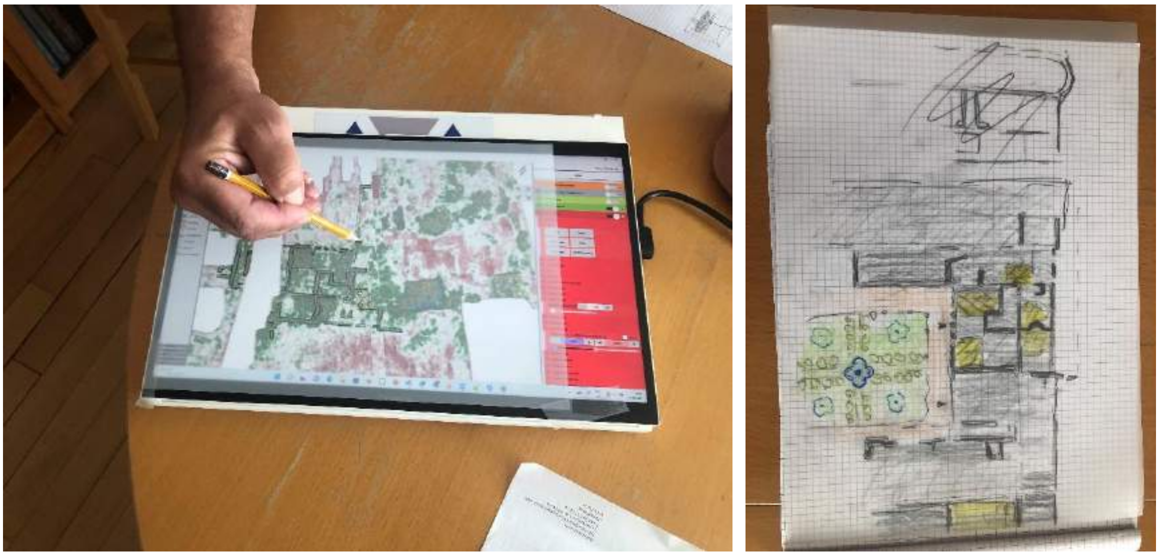


Fig. 27. Interpretation model of the apse after drawing a second contour polygon, extrusion, and apply a difference operation with the previous interpretation model.

The resulting interpretation tool more closely resembles 2D drawing applications. For more intuitive polygon extrusion an orthographic visualization mode was added. It ensures that interpretation polyhedrons are normal to the ground in the first 2D based interpretation stage. The new interpretation tool supports touch and stylus type input devices. Strokes are directly converted into polygons and optionally extrude to 3D space on the fly. Boolean operations are also be performed while drawing enabling an intuitive way of refining the interpretation model. A layer concept supports the simultaneous interpretation of multiple structures. Future work will include the specification of rules between the layers to ensure gapless intersection free floor plans, i.e., walls polygons drawn will automatically be cut out of floor polygons and so on. Figure 28 shows an example from Stonehenge. The 2,5 D polyhedrons from orthogonal views tool can be refined using arbitrary perspective views. Moreover, there are plans to use 2D, 2,5D and 3D interpretation polyhedrons for the initialization and guidance of automated segmentation algorithms.

Interpretation polygons and meshes can be exported to GIS at any time.

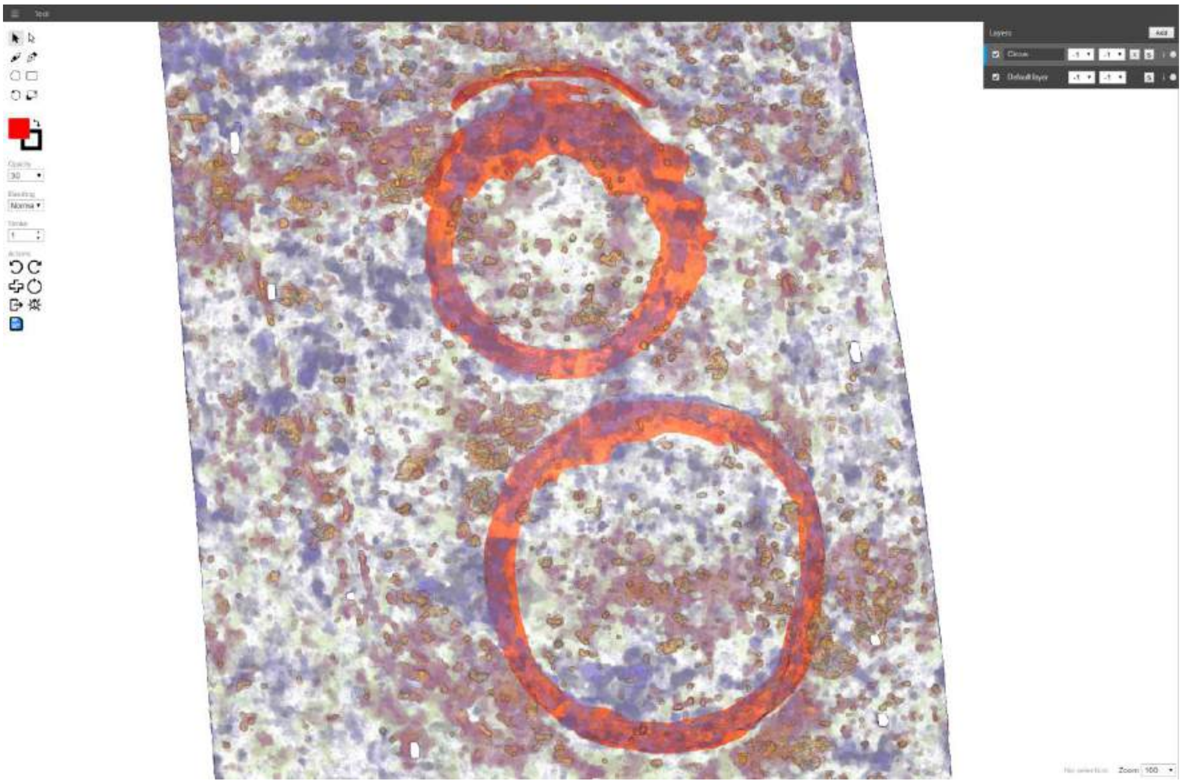


Fig. 28. Interpretation of circular structures in GPR data from Durrington Walls, UK. Stylus input allows for fine-grained contours.

7 Reconstruction and Simulation (SIM)

7.1 Open-source desktop planetarium *Stellarium*

Georg Zotti is co-developer of the popular Stellarium open-source desktop planetarium (https://stellarium.org). Stellarium's quarterly releases are downloaded by approx. 270.000-700.000 users, mostly by amateur astronomers, but also by peer researchers of cultural astronomy for which this program has become a standard tool.

After fixing the last significant shortcomings from the ephemeris modelling in 2021 (see report of last year), in 2022 Georg concentrated on upgrading the program source code to the new Qt6 programming framework before releasing its long-awaited version 1.0 on October 1st, 2022. Given that many older computers cannot cope with Qt6, we made sure to keep the source code still compatible with Qt5, and Qt5- and Qt6-based releases are made in parallel. The release was celebrated and presented during the Oxford-12 conference in La Plata:

- Georg Zotti and Wolfgang Neubauer. Advanced Virtual Archaeoastronomy. In Alexandro Lopez, editor, (Proc. ISAAC Oxford-XII, Oct. 31-Nov. 4, 2022), volume 4. SIA, to appear 2023.

The release of Version 1.0 triggered a few further publications:

- Georg Zotti, Alexander Wolf, and Susanne M. Hoffmann. Stellarium Approaching Maturity. In Susanne M. Hoffmann and Gudrun Wolfschmidt, editors, Astronomy in Culture - Cultures of Astronomy (Featuring the Proceedings of the Splinter Meeting at the Annual Conference of the Astronomische Gesellschaft, Sept. 14-16, 2021), volume 57 of Nuncius Hamburgensis: Beiträge zur Geschichte der Naturwissenschaften, chapter 2, pages 581–591. tredition, Hamburg, 2022. ISBN 978-3-347-71294-2.
- Georg Zotti and Alexander Wolf. Stellarium: Finally at 1.0! And Beyond. Journal of Skyscape Archaeology, 8(2):332–334, December 2022. ISSN 2055-3498. doi:10.1558/jsa.25608.

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

- Georg Zotti, Susanne M. Hoffmann, Doris Vickers, Rüdiger Schultz, and Alexander Wolf. Revisiting Star Names: Stellarium and the Ancient Skies Database. In (Proc. SEAC2021). Stara Zagora, to appear 2023.
- Doris Vickers, Georg Zotti, Susanne M. Hoffmann, and Rüdiger Schultz. Ancient Skies und Stellarium. In Susanne M. Hoffmann and Gudrun Wolfschmidt, editors, Astronomy in Culture - Cultures of Astronomy (Featuring the Proceedings of the Splinter Meeting at the Annual Conference of the Astronomische Gesellschaft, Sept. 14-16, 2021), volume 57 of Nuncius Hamburgensis: Beiträge zur Geschichte der Naturwissenschaften, chapter 2, pages 560–578. tredition, Hamburg, 2022.

Release of version 1.0 does not mean Stellarium is “finished”. Hardly any software of a certain complexity can be said to be. We (3-4 active developers, after 10 years of only 2) still have own ideas and demands, more ideas turn up in the user forum, bugs may appear, and some functionalities can still be improved. Versions 1.1 and 1.2 have also appeared in late 2022.

8 Spatio-temporal reasoning (STR)

8.1 Harris Matrix Composer (HMC)

In 2022 the LBI ArchPro continued to offer licenses for the Harris Matrix Composer v2.0b and received 35 requests from 17 different countries (Fig. 29 and 30). An interactive overview of the organizations that have acquired an HMC license in the past 14 years can be found under https://harrismatrixcomposer.com/stats/organizations.html.

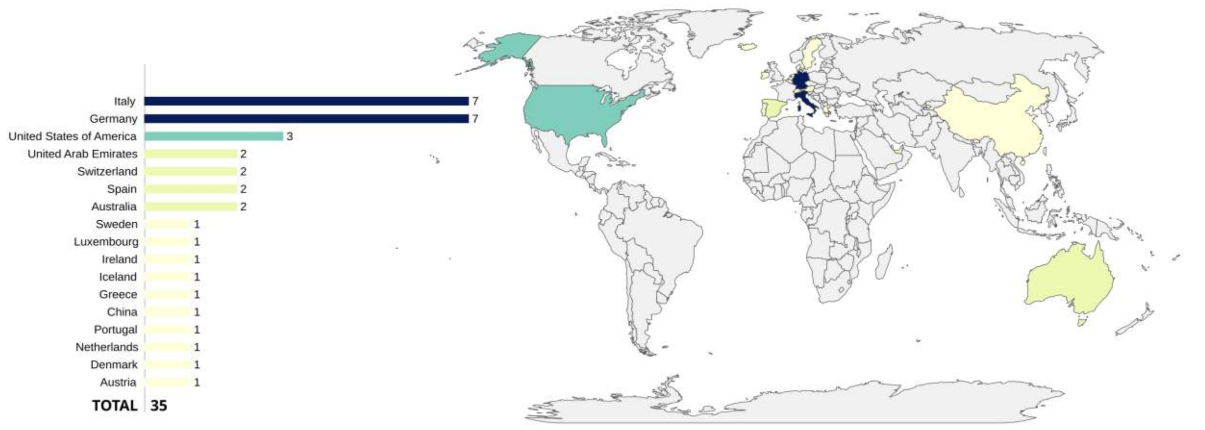


Fig. 29. HMC license requests in 2022 sorted by country.

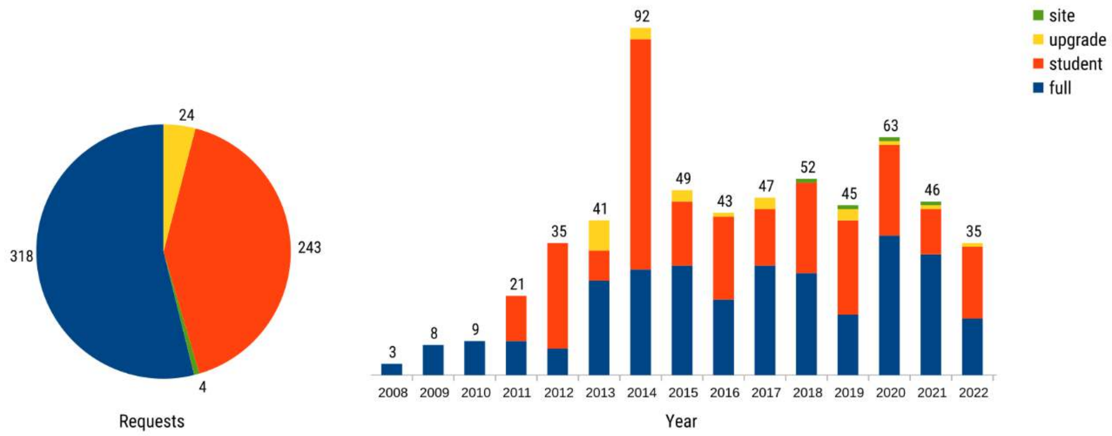


Fig. 30. Total requests of HMC licenses from 10/2008 to 12/2022.

8.2 Harris Matrix Composer Plus (HMC+)

In 2021, the main focus of HMC+ was on bug fixing and refactoring, as well as UI/UX improvements. In 2022, we continued to make small improvements to the application. These improvements included:

- Screenshot Tool: This feature enables users to take a screen shot of the whole application as a vector graphic. This is feature is also useful for creating quick, high-quality screen shots for the user manual.
- Importer Tool: The HMC+ Shapefile importer has undergone several improvements. Users can now import files with a drag and drop function and validate source data while also changing properties. The importer also supports hierarchical data, such as Stratigraphic Groups. In

upcoming releases, the importer will have support for hierarchical time models and dating, providing users with a more comprehensive and efficient tool (Fig. 31).

- **Layout Algorithm:** Users can now enable/disable transitive reduction of relations, providing them with more control over the graph structure. Additionally, undated units are now positioned at the bottom of the layer, making it easier for users to identify them. Recursive group layering, which previously caused layout problems in matrices with deeply nested groups, has been removed to improve overall layout efficiency.
- **Settings:** Users can now enable/disable the reduction of transitive relations
- **UI/UX:** We improved the print dialog, relation editor, and the search widget. We also started the implementation for multilingual support, which will be available in future releases.
- **Bug Fixes:** The HMC+ application has undergone several bug fixes to enhance its functionality. These include improvements to the validation process of cyclic relations, ensuring more accurate results. Visualization for absolute dated units has also been improved for better readability. Additionally, several I/O bugs have been fixed, enhancing the overall stability and performance of the application.
- **Migrations:** The Gradle build tool was upgrade to v7.3.3
- **Security:** Patched the vulnerability ([CVE-2021-45046] (https://cve.mitre.org/cgi-bin/cvename.cgi?name=CVE-2021-45046), also known as log4shell) of the logging library log4j
- **Experimental Features:** Started experimenting with fuzzy Allen intervals.

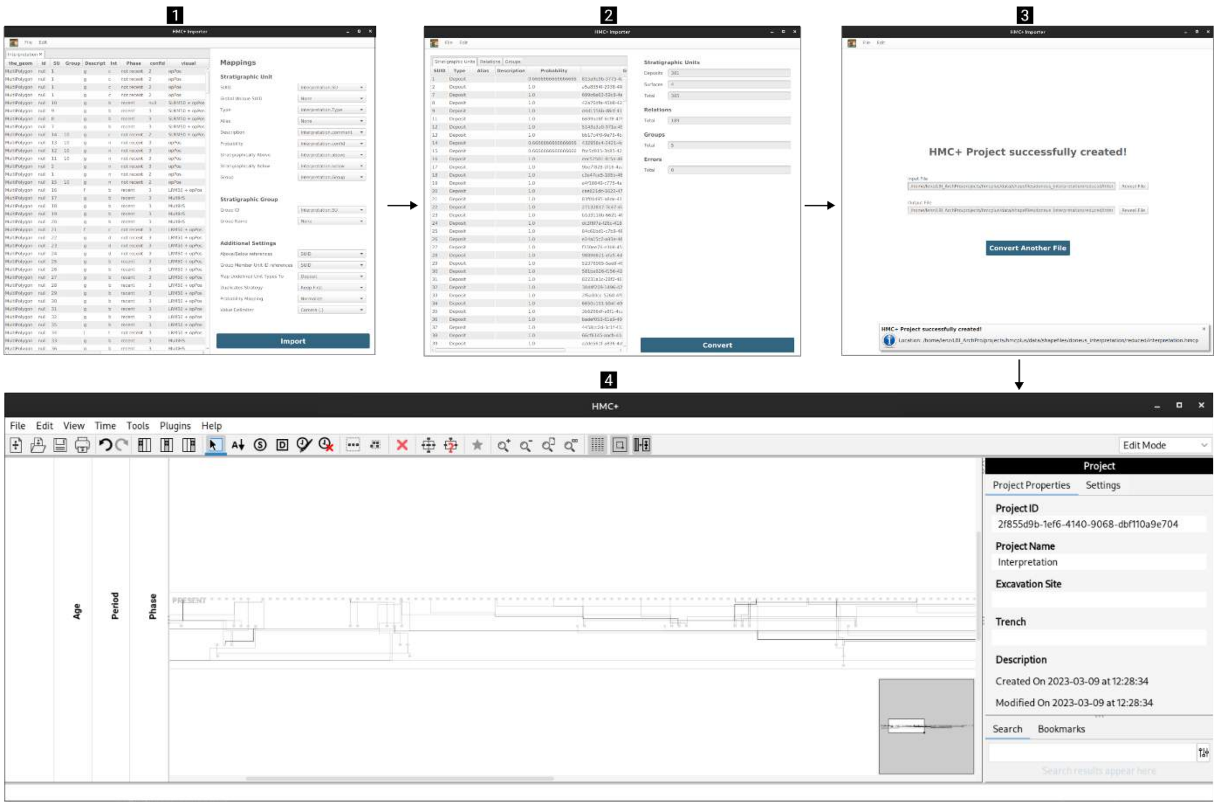


Fig. 31. From Shapefile to HMC+: A Step-by-Step Process of Geospatial Data Conversion and Validation to a Harris Matrix. (1) The original geospatial data from the Shapefile is imported, providing a foundation for the conversion process. (2) The importer provides a new view of the data, enabling users to validate and adjust the imported data as needed to ensure accuracy. (3) The data is successfully converted to HMC+ (4) The imported data is displayed in HMC+ with transitive reduction of relations disabled.

9 Dissemination and awareness (DISS)

9.1 Press releases

Schwarzenbach – Wenn Wälle brennen und Steine schmelzen (10-06-2022)

In June 2022, the LBI ArchPro issued a press release on latest research findings on the Bronze Age settlement at Schwarzenbach (Lower Austria). Current research by the LBI ArchPro and the University of Vienna shows that Schwarzenbach was already massively fortified a millennium before its Celtic period. A large Bronze Age settlement was enthroned on the "Burgberg" monitoring the copper trade which was located on the shortest route from the mining areas in the Rax to the distribution regions in the far reaches of Pannonia. The archaeological evidence shows that about 3500 years ago the Bronze Age fortification wall burnt down after a massive attack. The researchers have reconstructed the layout of the site and its destruction with the help of virtual reality (Fig. 32). In the exhibition at the Schwarzenbach Open-Air Museum, a video and a 3D-terrain-model explain in detail the construction of the reconstructed Bronze Age rampart.

Fig. 32. Virtual reconstruction of the Bronze Age settlement at Schwarzenbach (visualisation: Sandro Lochau).

9.2 TV productions

Universum History "Der Aufstieg der Habsburger - Schlacht am Marchfeld" (ORF2)

In summer 2021, a field team of the LBI ArchPro explored the traces of one of the biggest battles of the Middle Ages – the Battle on the Marchfeld between Dürnkrut and Jedenspeigen (Lower Austria) - using motorized magnetometer-sytems and UAV-based airborne Laserscanning (Fig. 33). An area of 2.5 km^2 was investigated and – while no features have been identified that can be attributed exclusively to the battle of 1278 - the results of the areas prospected represented excellent evidence of the potential of geomagnetic prospection on prehistoric and early historical areas for revealing connections between archaeological features and the landscape in which they are embedded.

Fig. 33. Scene from the TV documentary Universum History "Der Aufstieg der Habsburger – Schlacht am Marchfeld" showing aerial surveys with the LBI ArchPro's RIEGL LMS RiCOPTER at the battle site.

The project was also documented by a film team for a 45-minutes TV documentary on the famous battle. The Universum History documentary "Der Aufstieg der Habsburger – Schlacht am Marchfeld" featured footage of the institute's field campaign (Fig. 34) and scientific commentaries by the director and aired in January 2022. The broadcast also drew a lot of attention to the institute's research at the Marchfeld in the print and online media (see appendix "Media coverage 2022").

Fig. 34. Scene from the TV documentary Universum Universum History "Der Aufstieg der Habsburger – Schlacht am Marchfeld" showing LBI ArchPro staff W. Neubauer, M. Kucera and G. Stüttler discussing geophysical prospection results of the battle site.

9.3 Public science events

Forschungsfest Niederösterreich

Since 2017, the Province of Lower Austria (Department of Science and Research) has been organising the Forschungsfest NÖ, which is a biennial event for the whole family and invites interested people to come into direct contact with science and research. The LBI ArchPro has participated in all events at the Palais Niederösterreich in Vienna (2017, 2019 and 2022).

On September 30th 2022, more than 70 research exhibits presented current projects and interesting facts about science and research at the Forschungsfest NÖ. The LBI ArchPro focused on its research work within the Living Danube Limes project. Imagery on non-invasive archaeological methods and their application at project pilot sites as well as the virtual models produced for the Living Danube Limes app were presented on an interactive touchscreen table suitable for communicating the respective project outputs to the visitors (Fig. 35).

Fig. 35. Interested children and adults at the LBI ArchPro exhibit at the Forschungsfest NÖ 2022.

A short video featuring footage of the geophysical surveys that were conducted at five pilot sites in fall 2021 and scenes from the Austrian leg of the ship cruise was exclusively produced for this event and presented on another screen at the exhibit. Promotional project material (leaflets, pens, writing pads) was placed on display for free withdrawal.

The event was hosted by the federal governor of the Province of Lower Austria, Johanna Mikl-Leitner, who also paid an exclusive visit to the institute's exhibit during her walkabout (Fig. 36).

Fig. 36. Johanna Mikl-Leitner, governor of the Province of Lower Austria, visits the LBI ArchPro exhibit at the Forschungsfest NÖ 2022.

Lange Nacht der Forschung

The “Lange Nacht der Forschung” is the largest event for science and research in Austria. The aim is to bring science and research closer to the public nationwide. After a Covid-related hiatus, the event could take place face-to-face again on May 20th 2022.

The LBI ArchPro was represented with an information screen at the MAMUZ museum at the castle Schloss Asparn/Zaya (Lower Austria). On the screen, a series of selected films provided an insight into how the researchers are investigating Neolithic circular ditch enclosures (Kreisgrabenanlagen) with the help of latest prospection technology and how they are reconstructing them on the computer as virtual reconstructions (Fig. 37).

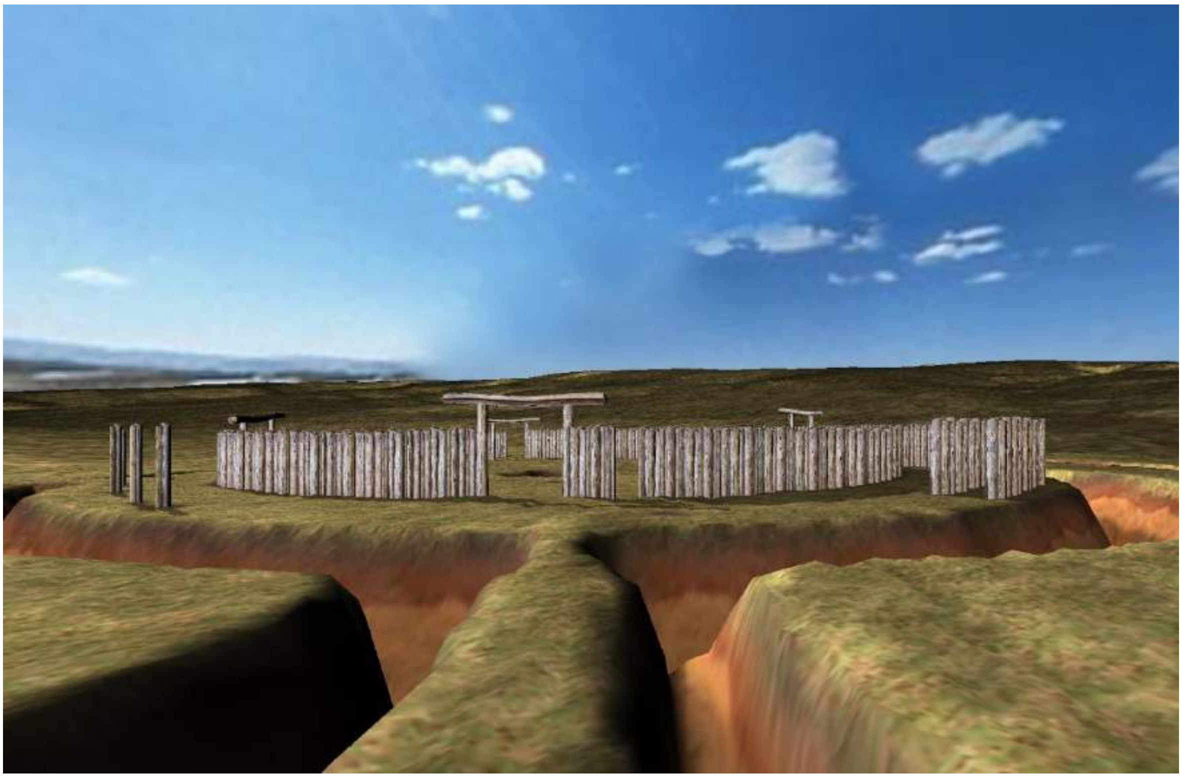


Fig. 37. 3D visualisation of the reconstructed Kreisgrabenanlage Steinabrunn as presented at the Lange Nacht der Forschung.

9.4 Federal Stud Piber dissemination project

Piber Digital – website

Development of a public project website (https://piber.lbi-archpro.org/) began while the survey campaign was still underway in November 2020, and content has since been continuously updated and added to in line with project progress (Fig. 38).

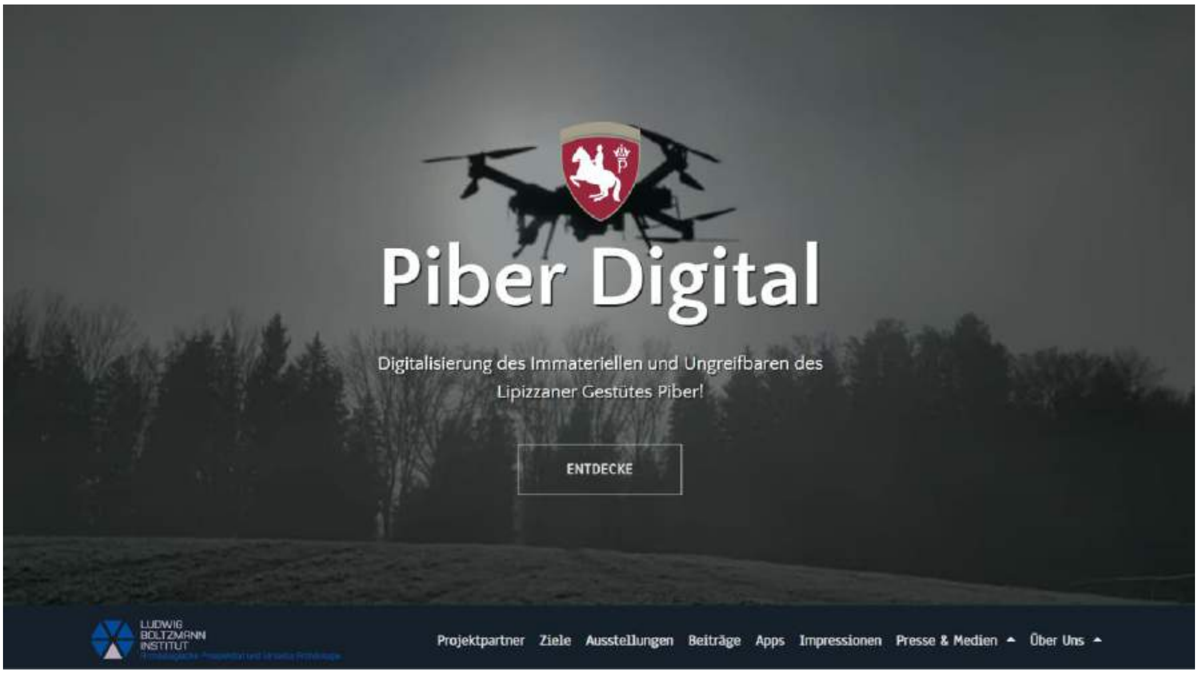


Fig. 38. Homepage of the Piber Digital project.

The main menu of the website is divided into the following sections:

- Project: Here, the project partners, methods, project goal and progress are documented.
- Exhibitions: Additional digital content and information is offered in parallel to the real exhibition on site.
- Contributions: Ongoing articles and videos on a wide variety of topics related to the stud farm and project progress are published here. This includes articles on important buildings, such as Church of St. Andreas, or the opening of the museum. In addition, there are short articles on the survey methods used.
- Interactive contributions: Interactive 3D models, maps and 3D point clouds are published here.
- Apps: For the exhibition "Folge der Herde" the apps "Folge Sigi" and "Folge der Herde" for Android and iOS were developed and made available for download via the project website.
- Impressions: Impressions of the field work, PR pictures, landscape pictures as well as pictures of Lipizzaners are published.
- Press and media: Press releases and press material such as pictures, texts and videos are made available here. Furthermore, the diverse media coverage of the project is collected in a press archive.

Digital tour

A central part of the website is the digital tour of the stud in Piber. In an interactive map, visitors can explore important stations on the stud. The interactive map was implemented using Leaflet, a free JavaScript framework for GIS applications (Fig. 39). For this purpose, a custom plugin for Hugo was developed and integrated into the website. Points on the map can be linked to important information. This includes Name, location (GPS coordinates), description, video, 3D model, point cloud or related articles.

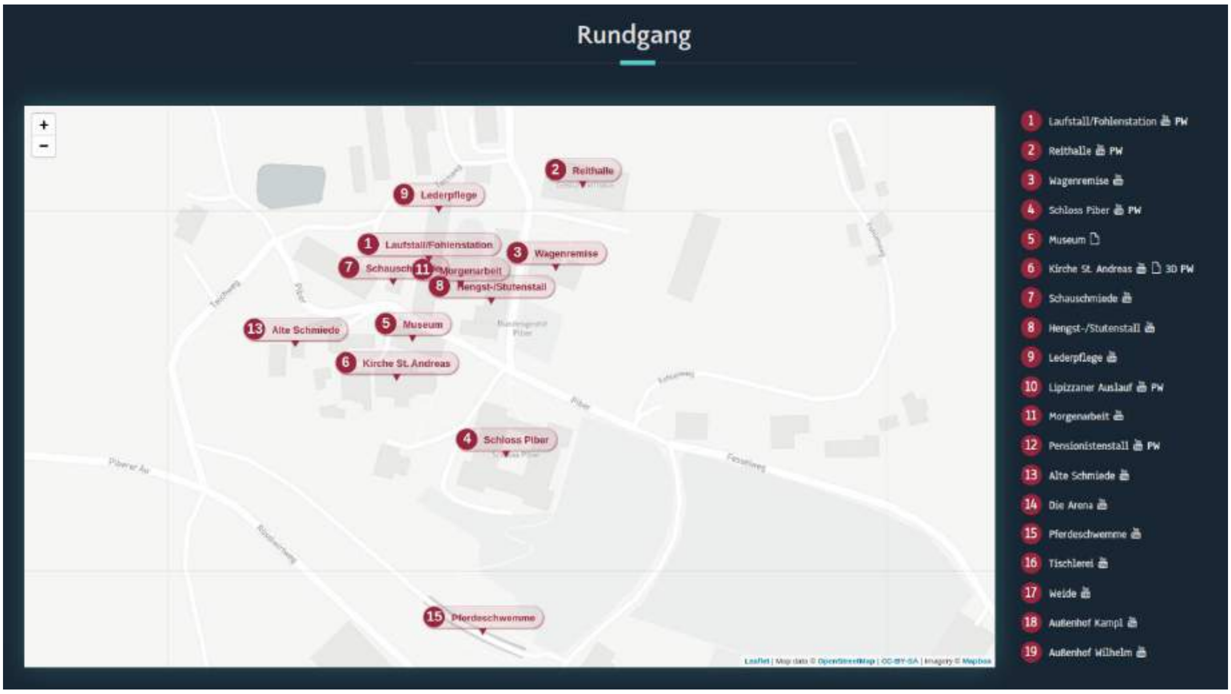


Fig. 39. An interactive tour of the stud in Piber has been implemented on the website.

In addition, the tour was also implemented on YouTube. Here, visitors can click their way from station to station: https://www.youtube.com/playlist?list=PLAJQ_9xDM55FSzsDNiuNcwtd5qhutyBnd)

Interactive posts

In the Interactive Posts section, visitors can digitally explore the landscape of Piber. For this purpose, the 3D point cloud viewer Potree (https://github.com/potree/potree) has been integrated into the website. With Potree it is possible to interactively move through the point cloud, which was acquired by airborne laser scanning (Fig. 40). Various filters can also be applied, such as filtering out vegetation, in order to view the terrain without trees. For this purpose, the ALS data were fittingly integrated into the website in several viewpoints (scenes). This presentation gives visitors to the website an exciting insight into remote sensing using laser scanners.

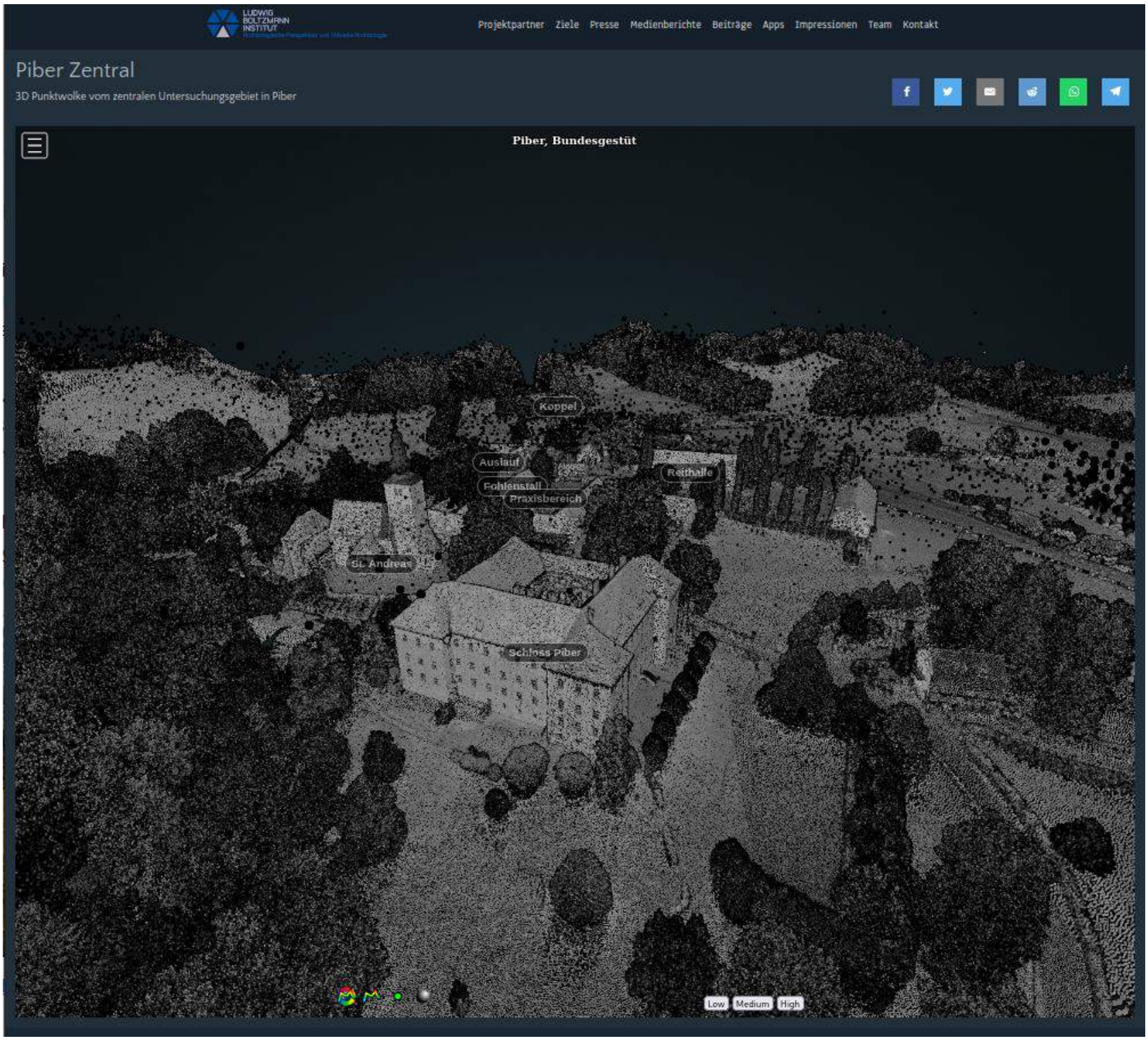


Fig. 40. A 3D pointcloud of the Piber central area can be viewed with Potree on the website.

Exhibition

The exhibition in the Schüttkasten Piber is also to be expanded in the future with additional content via the augmented reality application. However, the size of the application is a limiting factor. Therefore, the idea is to make the corresponding content for the expansion of the museum tour available via the project homepage.

In addition, this access also offers the possibility to integrate the exhibition as a virtual tour. Therefore, a first prototype for a virtual interactive exhibition "Follow the Herd" (https://piber.lbi-archpro.org/exhibition/folge_der_herde) was implemented with the Javascript framework revealjs. Here, different zones of the exhibition can be explored digitally (Fig. 41).

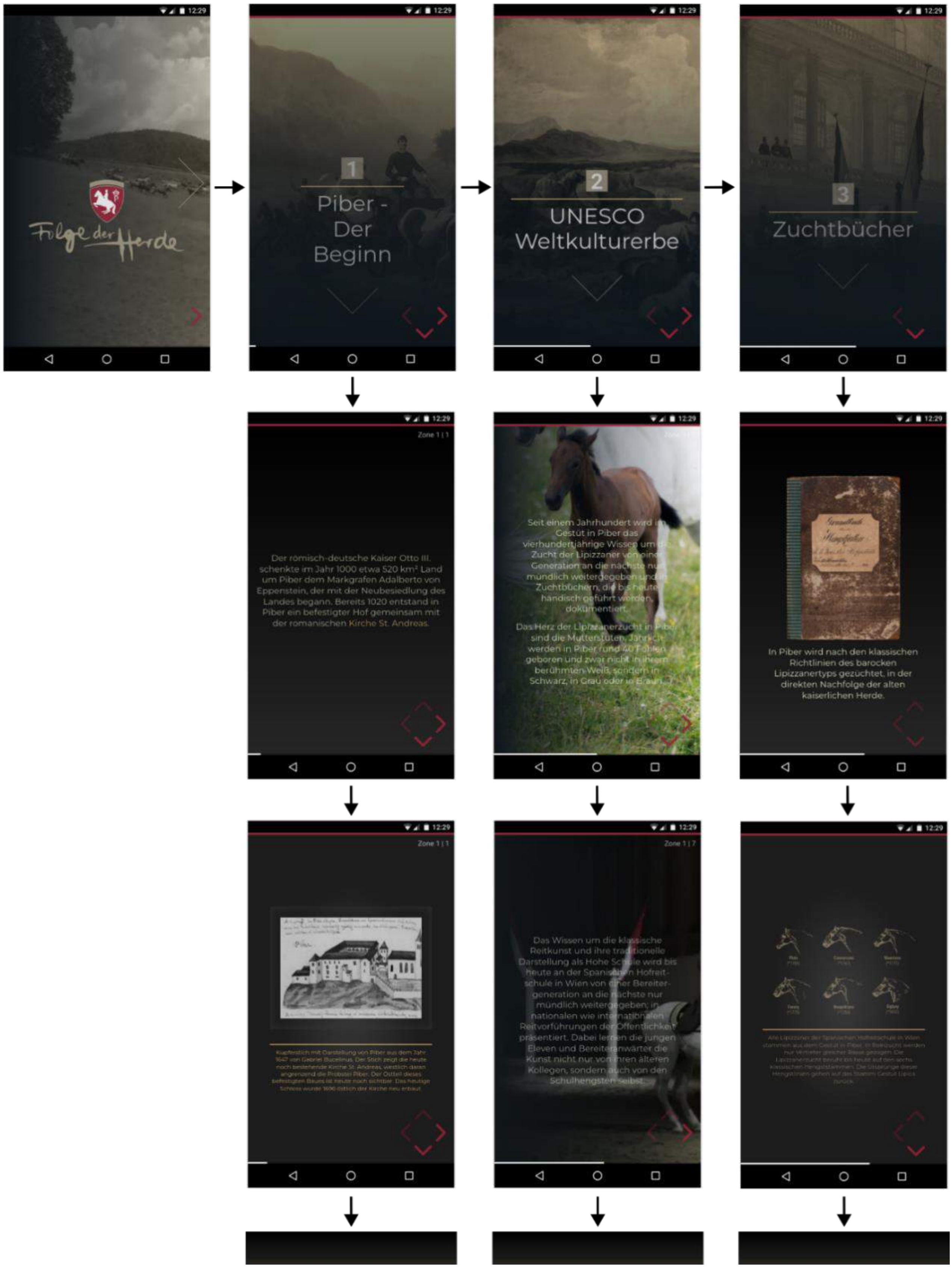


Fig. 41. The diagram above shows the mobile version with three stations (Piber - The Beginning, UNESCO World Heritage, Breeding Books) and the first two screens.

Technology

To ensure a sustainable, cost-effective and future-proof development of the website, only open source and freely available tools and technologies were used. All areas - from image processing, graphic design, video editing to programming - were implemented with open-source tools.

- For image processing and graphic design Inkscape (https://inkscape.org) and Gimp (https://www.gimp.org) were used.
- For video editing and compression ffmpeg (https://ffmpeg.org) and Openshot (https://www.openshot.org) were used.
- The open-source editor Visual Studio Code (https://code.visualstudio.com) was used to develop the website. The website itself is based on the static website generator Hugo (https://gohugo.io) and the template meghna-hugo (https://github.com/themefisher/meghna-hugo), as well as the free Javascript libraries jquery (https://jquery.com), photo-sphere-viewer (https://photo-sphere-viewer.js.org), leaflet (https://leafletjs.com) and revealjs (https://revealjs.com).

In terms of responsive design, the content and interactions were developed and optimized for different devices and resolutions. Visitors can thus comfortably explore the site from mobile devices such as smartphones and tablets and from PCs and laptops. An integrated panorama viewer (Photo Sphere Viewer) enables interactive panoramas with 360-degree panoramic views (Fig. 42).

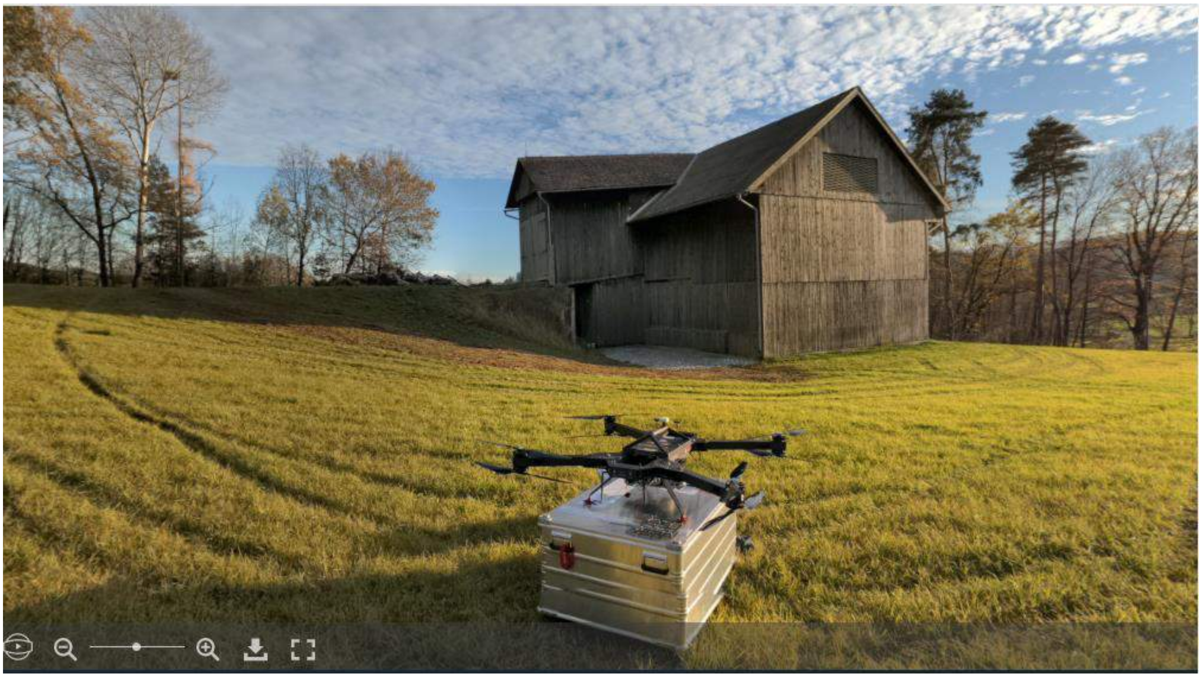


Fig. 42. Starting point of a drone mission as shown in the Photo Sphere Viewer.

9.5 Scientific publications and presentations 2022

Articles

Bornik, Alexander; Neubauer, Wolfgang (2022): 3D Visualization Techniques for Analysis and Archaeological Interpretation of GPR Data. In: Remote Sensing 14 (7), S. 1709. DOI: 10.3390/rs14071709.

Doneus, Michael; Banaszek, Łukasz; Verhoeven, Geert Julien Joanna (2022): The Impact of Vegetation on the Visibility of Archaeological Features in Airborne Laser Scanning Datasets from Different Acquisition Dates. In: Remote Sensing 14 (4), S. 858. DOI: 10.3390/rs14040858.

Doneus, Michael; Neubauer, Wolfgang; Filzwieser, Roland; Sevara, Christopher (2022): Stratigraphy from Topography II. The Practical Application of the Harris Matrix for the GIS-based Spatio-temporal Archaeological Interpretation of Topographical Data. In: ArchA (Archaeologia Austriaca) 106/2022, S. 223–252. DOI: 10.1553/archaeologia106s223.

Filzwieser, Roland; Ruß, David; Kucera, Matthias; Doneus, Michael; Hasenhündl, Gerhard; Verhoeven, Geert Julien Joanna et al. (2022): History and Archaeology in Discourse on the Dernberg–Reconstructing the Historical Landscape of a Medieval Motte-and-Bailey Castle and Deserted Village. In: Heritage 5 (3), S. 2123–2141. DOI: 10.3390/heritage5030111.

Lobisser, Wolfgang F. A. (2022): Das Rekonstruktionsmodell einer frühmittelalterlichen Rotunde mit Apsis im MAMUZ in Niederösterreich nach einem archäologischen Befund aus Pohansko in Mähren. In: Experimentelle Archäologie in Europa (21), S. 109–128.

Neubauer, Wolfgang; Traxler, Christoph; Bornik, Alexander; Lenzhofer, Andreas (2022): Stratigraphy from Topography I. Theoretical and Practical Considerations for the Application of the Harris Matrix for the GIS-based Spatio-temporal Archaeological Interpretation of Topographical Data. In: ArchA (Archaeologia Austriaca) 106, S. 203–221. DOI: 10.1553/archaeologia106s203.

Schneidhofer, Petra; Tonning, Christer; Cannell, Rebecca J. S.; Nau, Erich; Hinterleitner, Alois; Verhoeven, Geert Julien Joanna et al. (2022): The Influence of Environmental Factors on the Quality of GPR Data: The Borre Monitoring Project. In: Remote Sensing 14 (14), S. 3289. DOI: 10.3390/rs14143289.

Teichmann, Michael; Wallner, Mario; Pollhammer, Eduard; Neubauer, Wolfgang (2022): Untersuchungen zu einer möglichen Fullonica in der Zivilstadt von Carnuntum. In: Archäologisches Korrespondenzblatt 52 (1), S. 113–125.

Wallner, Mario; Doneus, Michael; Kowatschek, Ingrid; Hinterleitner, Alois; Köstelbauer, Felix; Neubauer, Wolfgang (2022): Interdisciplinary Investigations of the Neolithic Circular Ditch Enclosure of Velm (Lower Austria). In: Remote Sensing 14 (11), S. 2657. DOI: 10.3390/rs14112657.

Wild, Benjamin; Verhoeven, Geert Julien Joanna; Wieser, Martin; Ressl, Camillo; Schlegel, Jona; Wogrin, Stefan et al. (2022): AUTOGRAF—AUTomated Orthorectification of GRAFfiti Photos. In: Heritage 5 (4), S. 2987–3009. DOI: 10.3390/heritage5040155.

Conference proceedings

Lobisser, Wolfgang F. A.; Neubauer, Wolfgang (2022): Dreißig Jahre archäologische Forschungen und Public Archaeology in Schwarzenbach in der Buckligen Welt in Niederösterreich. Prospektionen, Archäologische Grabungen, Experimentelle Archäologie und deren Implementierung für Scientific Events und Vermittlungskonzepte. In: Alfred Weidinger und Jutta Leskovar (Hg.): INTERPRETIERTE EISENZEITEN. Fallstudien, Methoden, Theorie. Tagungsbeiträge der 9. Linzer Gespräche zur interpretativen Eisenzeitarchäologie. Linz, Austria (Studien zur Kulturgeschichte von Oberösterreich, 51), S. 227–246.

Nocerino, Erica; Menna, Fabio; Verhoeven, Geert Julien Joanna (2022): Good vibrations? How image stabilisation influences photogrammetry. In: Int. Arch. Photogramm. Remote Sens. Spatial Inf. Sci. XLVI-2/W1-2022, S. 395–400. DOI: 10.5194/isprs-archives-XLVI-2-W1-2022-395-2022.

Verhoeven, Geert Julien Joanna; Wild, Benjamin; Schlegel, Jona; Wieser, Martin; Pfeifer, Norbert; Wogrin, Stefan et al. (2022): Project INDIGO – document, disseminate & analyse a graffiti-scape. In: Int. Arch. Photogramm. Remote Sens. Spatial Inf. Sci. XLVI-2/W1-2022, S. 513–520. DOI: 10.5194/isprs-archives-XLVI-2-W1-2022-513-2022.

Dissertations

Aldrian, Lisa (2022): The stratigraphy of the hermitage on the Falkenstein. Master thesis. Universität Wien, Wien, Austria.

Miscellaneous

Verhoeven, Geert Julien Joanna; Carloni, Massimiliano; Schlegel, Jona; Trognitz, Martina; Wild, Benjamin; Wogrin, Stefan et al. (2022): goINDIGO 2022 international graffiti symposium: document | archive | disseminate graffiti-scapes. Book of abstracts. project INDIGO. Vienna. Online available under: https://go-indigo.eu/wp-content/uploads/2022/05/goINDIGO2022_bookOfAbstracts.pdf

Talks

Filzwieser, Roland (2022): Overgrown Villages: A Stratigraphic Perspective on Deserted Medieval Villages and Their Surrounding Landscapes. International Medieval Congress 2022. Institute for Medieval Studies. University of Leeds. Leeds, UK, 06.07.2022.

Kucera, Matthias; Doneus, Michael; Coolen, Joris; Neubauer, Wolfgang (2022): Hornsburg: Landschaftsarchäologische Untersuchung einer mittelneolithischen Siedlungskammer in Niederösterreich. rondel'22 - Ritualarena, Kalenderbau oder performative Architektur? Neue Hypothesen und Forschungen zu neolithischen Kreisgrabenanlagen 5000-4500 BC. Institut für Prähistorische Archäologie, Freie Universität Berlin. online event.

Kucera, Matthias; Salisbury, Roderick B.; Schneidhofer, Petra; Kainz, Jakob; Neubauer, Wolfgang (2022): Naturwissenschaftliche Untersuchung der Grabenfüllung der mittelneolithischen Kreisgrabenanlage Hornsburg 1 (NÖ). rondel'22 - Ritualarena, Kalenderbau oder performative Architektur? Neue Hypothesen und Forschungen zu neolithischen Kreisgrabenanlagen 5000-4500 BC. Institut für Prähistorische Archäologie, Freie Universität Berlin. online event, 27.01.2022.

Lobisser, Wolfgang; Neubauer, Wolfgang (2022): Experimentalarchäologische Rekonstruktion der mittel-neolithischen Kreisgrabenanlage Schletz – Zur aktuellen Situation siebzehn Jahre später. rondel'22 - Ritualarena, Kalenderbau oder performative Architektur? Neue Hypothesen und Forschungen zu neolithischen Kreisgrabenanlagen 5000-4500 BC. Institut für Prähistorische Archäologie, Freie Universität Berlin. online event, 27.01.2022.

Löcker, Klaus; Kastowsky, Karolin; Neubauer, Wolfgang (2022): Die dreifache mittelneolithische Kreisgrabenanlage von Immendorf (NÖ). rondel'22 - Ritualarena, Kalenderbau oder performative Architektur? Neue Hypothesen und Forschungen zu neolithischen Kreisgrabenanlagen 5000-4500 BC. Institut für Prähistorische Archäologie, Freie Universität Berlin. online event, 27.01.2022.

Molada-Tebar, Adolfo; Verhoeven, Geert Julien Joanna (2022): Achieving colour-accurate data from images: challenges and solutions. goINDIGO 2022 symposium. project INDIGO. FLEXraum. Vienna, Austria, 11.05.2022.

Neubauer, Wolfgang (2022): Älter als Stonehenge – Die mittelneolithischen Kreisgrabenanlagen. rondel'22 - Ritualarena, Kalenderbau oder performative Architektur? Neue Hypothesen und

Forschungen zu neolithischen Kreisgrabenanlagen 5000-4500 BC. Institut für Prähistorische Archäologie, Freie Universität Berlin. Public keynote lecture. online event, 27.01.2022.

Neubauer, Wolfgang; Schiel, Hannes (2022): Die drei mittelneolithischen Kreisgrabenanlagen von Rechnitz (Bgld). rondel'22 - Ritualarena, Kalenderbau oder performative Architektur? Neue Hypothesen und Forschungen zu neolithischen Kreisgrabenanlagen 5000-4500 BC. Institut für Prähistorische Archäologie, Freie Universität Berlin. online event, 27.01.2022.

Ruß, David; Schlegel, Jona; Riederer, Katharina; Kucera, Matthias; Wallner, Mario; Schiel, Hannes et al. (2022): Eggendorf am Walde (NÖ) – Die Kreisgrabenanlage und das Fortleben einer bandkeramischen Großsiedlung im Mittelneolithikum. rondel'22 - Ritualarena, Kalenderbau oder performative Architektur? Neue Hypothesen und Forschungen zu neolithischen Kreisgrabenanlagen 5000-4500 BC. Institut für Prähistorische Archäologie, Freie Universität Berlin. online event, 27.01.2022.

Sauter, Klara; Kucera, Matthias; Neubauer, Wolfgang (2022): Aktuelle Untersuchungen zur dreifachen mittelneolithischen Kreisgrabenanlage Hornsburg 1 (NÖ). Forschungen im Rahmen der LBI Case Study „Mikroregion Kreuttal“. rondel'22 - Ritualarena, Kalenderbau oder performative Architektur? Neue Hypothesen und Forschungen zu neolithischen Kreisgrabenanlagen 5000-4500 BC. Institut für Prähistorische Archäologie, Freie Universität Berlin. online event, 27.01.2022.

Schlegel, Jona; Carloni, Massimiliano; Wogrin, Stefan; Verhoeven, Geert Julien Joanna (2022): Towards a Graffiti Thesaurus in SKOS. goINDIGO 2022 symposium. project INDIGO. FLEXraum. Vienna, Austria, 12.05.2022.

Verhoeven, Geert Julien Joanna; Schlegel, Jona; Wieser, Martin; Wogrin, Stefan (2022): Discovering & recording new graffiti within project INDIGO. goINDIGO 2022 symposium. project INDIGO. FLEXraum. Vienna, Austria, 11.05.2022.

Wallner, Mario; Filzwieser, Roland; Löcker, Klaus; Schiel, Hannes; Ruß, David; Trausmuth, Tanja; Neubauer, Wolfgang (2022): Die Kreisgrabenanlagen des Leithagebirges (Niederösterreich/ Burgenland). rondel'22 - Ritualarena, Kalenderbau oder performative Architektur? Neue Hypothesen und Forschungen zu neolithischen Kreisgrabenanlagen 5000-4500 BC. Institut für Prähistorische Archäologie, Freie Universität Berlin. online event, 27.01.2022.

Wallner, Mario; Neubauer, Wolfgang; Hladik, Constantin; Kowatschek, Ingrid; Doneus, Michael; Hinterleitner, Alois et al. (2022): Interdisziplinäre Untersuchungen der dreifachen Kreisgrabenanlage von Velm (NÖ). rondel'22 - Ritualarena, Kalenderbau oder performative Architektur? Neue Hypothesen und Forschungen zu neolithischen Kreisgrabenanlagen 5000-4500 BC. Institut für Prähistorische Archäologie, Freie Universität Berlin. online event, 27.01.2022.

Wild, Benjamin; Verhoeven, Geert Julien Joanna; Ressl, Camillo; Otepka-Schremmer, Johannes; Pfeifer, Norbert (2022): Towards the automatic production of graffiti orthophotos. goINDIGO 2022 symposium. project INDIGO. FLEXraum. Vienna, Austria, 12.05.2022.

Wild, Benjamin; Verhoeven, Geert Julien Joanna; Schlegel, Jona; Wieser, Martin; Pfeifer, Norbert; Wogrin, Stefan et al. (2022): Project INDIGO - document, disseminate & analyse a graffiti-scape. 3D-ARCH'2022 - 3D Virtual Reconstruction and Visualization of Complex Architectures – 9th International Workshop. MAMU – Mantova Multicentre “Antonino Zaniboni”. Mantova, Italy, 03.02.2022.

Zotti, Georg; Neubauer, Wolfgang (2022): Sonnen- oder talwärts? Zur Orientierungsfrage um die Zugänge der mittelneolithischen Kreisgrabenanlagen in Niederösterreich. rondel'22 - Ritualarena, Kalenderbau oder performative Architektur? Neue Hypothesen und Forschungen zu neolithischen Kreisgrabenanlagen 5000-4500 BC. Institut für Prähistorische Archäologie, Freie Universität Berlin. online event, 27.01.2022.

Zotti, Georg (2022): Stellarium for Research and Outreach. School for Young Researchers at the ISAAC Oxford-XII Conference (24.-28.10.). La Plata, 2022.

Zotti, Georg (2022): Developing Skycultures for Stellarium. School for Young Researchers at the ISAAC Oxford-XII Conference (24.-28.10.). La Plata, 2022.

Zotti, Georg (2022): The Secrets of Accurate Landscape Configuration in Stellarium. School for Young Researchers at the ISAAC Oxford-XII Conference (24.-28.10.). La Plata, 2022.

Poster

Wieser, Martin; Verhoeven, Geert Julien Joanna; Wild, Benjamin (2022): Acquiring centimetre-accurate camera coordinates in project INDIGO. 3rd Heritage Science Austria Meeting. Heritage Science Austria. Akademie der bildende Künste Wien. Vienna, Austria, 23.09.2022.

Wild, Benjamin; Verhoeven, Geert Julien Joanna; Wieser, Martin; Wogrin, Stefan; Pfeifer, Norbert (2022): How project INDIGO automatically turns graffiti photos into orthophotomaps. 3rd Heritage Science Austria Meeting. Heritage Science Austria. Akademie der bildende Künste Wien. Vienna, Austria, 23.09.2022.

10 Training and teaching (TRAIN)

10.1 University field schools

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

The prehistoric site Königsberg in Tieschen is one of the largest fortified settlements in southern Styria. The hilltop settlement, located on the summit of the Königsberg, dates to the Late Bronze Age and covers an area of about 10 ha. The fortification, consisting of ditches and earthworks, is still clearly visible in the landscape. The new research project will be the first to investigate the prehistoric settlement using interdisciplinary methods. Last year, the project was successfully launched with a high-resolution GPR survey and a targeted research excavation of a selected area within the settlement. The project has had a very positive impact on the local community and has been well received by the media.

In close cooperation with the municipality of Tieschen and the University of Vienna, the archaeological investigation of the 150 m2 area was continued in July 2022. Last year's excavations revealed mainly eroded layers of the adjacent rampart, but no significant archaeological structures. This season, the remains of three Bronze Age houses were uncovered underneath, as well as numerous finds dating from Bronze Age to Neolithic periods. Using image-based modelling and terrestrial laser scanning, all archaeological features were digitally documented in three dimensions.

The four-week field school was attended by seven advanced-level students, three interns and one student intern funded by the FFG Talents Programme. The field school participants were trained in the different areas of archaeological fieldwork and digital documentation (Fig. 43).

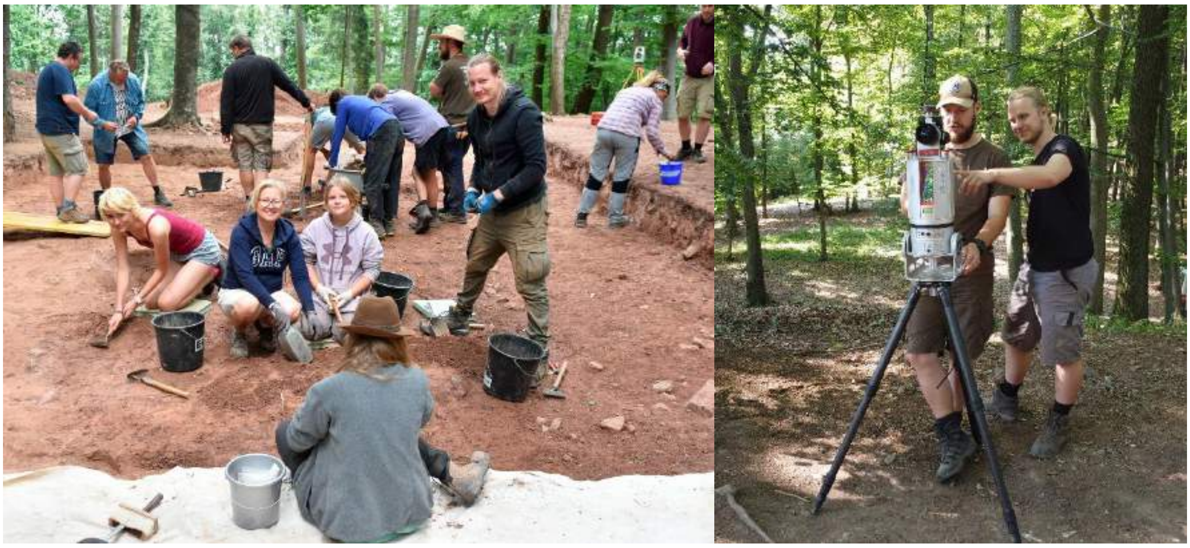


Fig. 43. Left: Students working at the Königsberg site. Right: Terrestrial laserscanning at the Königsberg site.

As an important aspect of the project is public outreach and participation, interested volunteers were encouraged to participate. Several local volunteers joined the team and assisted the archaeologists on a daily basis. Additionally, weekly open excavation days were organised, where visitors took part in guided tours and had a look at the best finds from the ongoing excavation.

Public presentations

- 26.03.2022 – Presentation for local community (Tieschen, Königsberghalle).
- 29.04.2022 – Presentation: Archäologie in der Steiermark. Neue Forschungen und Ergebnisse (Graz, Archäologiemuseum).
- 15.10.2022 – Presentation: Streifzüge durchs Vulkanland von Urania Graz (Tieschen, Königsberg Research).

10.2 Internships

In 2022 the LBI ArchPro again offered several opportunities to students to gain research and work experience in the fields of archaeological prospection and virtual archaeology. The interns were guided by the dedicated LBI ArchPro team as they worked on their respective internship projects.

Archaeological excavation and 3D documentation of archaeological excavation data

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

- The archaeological field assistants included David Simböck, Katharina Riederer, Valentina Graf, Elias Bele and Tatjana Reuss.
- Marion Hochleitner completed a 4-week school student's internship funded by the FFG Talente programme. During her internship, she was involved in all aspects of archaeological excavation and digital documentation (Fig. 44). Her excellent report, which was supervised by Wolfgang Neubauer and Ingrid Kowatschek, was selected by the FFG as one of the top 20 internship reports. The Federal Ministry for Climate Action, Environment, Energy, Mobility, Innovation and Technology will present the award to the team in March 2023.

Fig. 44. FFG Talents intern Marion Hochleitner at the Königsberg site.

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

Supervisors: Wolfgang Neubauer, Ingrid Kowatschek

10.3 University lectures

Table 1 lists the academic lectures and courses held by LBI ArchPro staff at the University of Vienna in 2022:

Wolfgang Neubauer	Summer 2022	• 060047 KU Theory and Practice of Archaeological Stratigraphy & Advanced Surveying • 060074 LP Training excavation Tieschen • 060078 SE Thesis Seminar • 060081 SE Selected topics on the late Iron Age in Scandinavia (400-1050)
	Winter 2022	• 060060 SE Archaeological Prospection – Theory & Practice • 060061 SE Stonehenge – Biography of an archaeological landscape
Matthias Kucera	Winter 2022 Summer 2022	• 060041 VO Experimental Archaeology • 060057 UE Experimental Archaeology: practical course •
Klaus Löcker	Summer 2022	• 060032 KU Introduction to Surveying and Stratigraphy •
Geert Verhoeven	Winter 2022	• 060069 KU Image-based modelling for archaeology •
Michael Doneus	Winter 2022	• 060051 UE GIS-Application for Archaeologists • 060059 SE Site and Landscape • 060065 VU Scientific Practice • 060066 SE Thesis Seminar • 060074 UE Airborne Laser Scanning (LiDAR) for archaeologists
	Summer 2022	• 060038 UE GIS-Application for Archaeologists • 060039 VO Landscape archaeology • 060046 VU Scientific Practice • 060077 SE thesis Seminar • 060083 UE Practical application of aerial archaeology

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

11 Third party funded research projects

11.1 Living Danube Limes

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

The project is centred around the Roman Danube Limes as transnational cultural heritage of enormous significance. Spanning the whole Danube region, the project aims at further developing and enhancing the connecting aspects of the Roman heritage sites along the river, thus, fostering a common sense of togetherness in the Danube Region.

Virtual reality reconstructions of selected pilot sites

In fall 2021, the LBI ArchPro had investigated selected Roman sites in five project partner countries using geophysical prospection methods. The acquired geophysical data contributed to the subsequent creation and implementation of VR reconstructions for pilot sites.

The LBI ArchPro was responsible for collecting and processing data for those pilot sites which have been surveyed with geophysical prospection and photogrammetric methods (Slovakia, Hungary, Croatia, Bulgaria, Romania). Subsequently, VR-3D-reconstructions were created for these pilot sites including hypothetical reconstructions of the sites (Iža, Százhalombatta, Vidin, Sacidava) and small-scale 3D models of finds (Kopačevo) in collaboration with the Slovak Technical University Bratislava. Input for the large-scale reconstructions were the results of the geophysical prospection data as well as digital surface models acquired through UAV-based image-based modelling data.

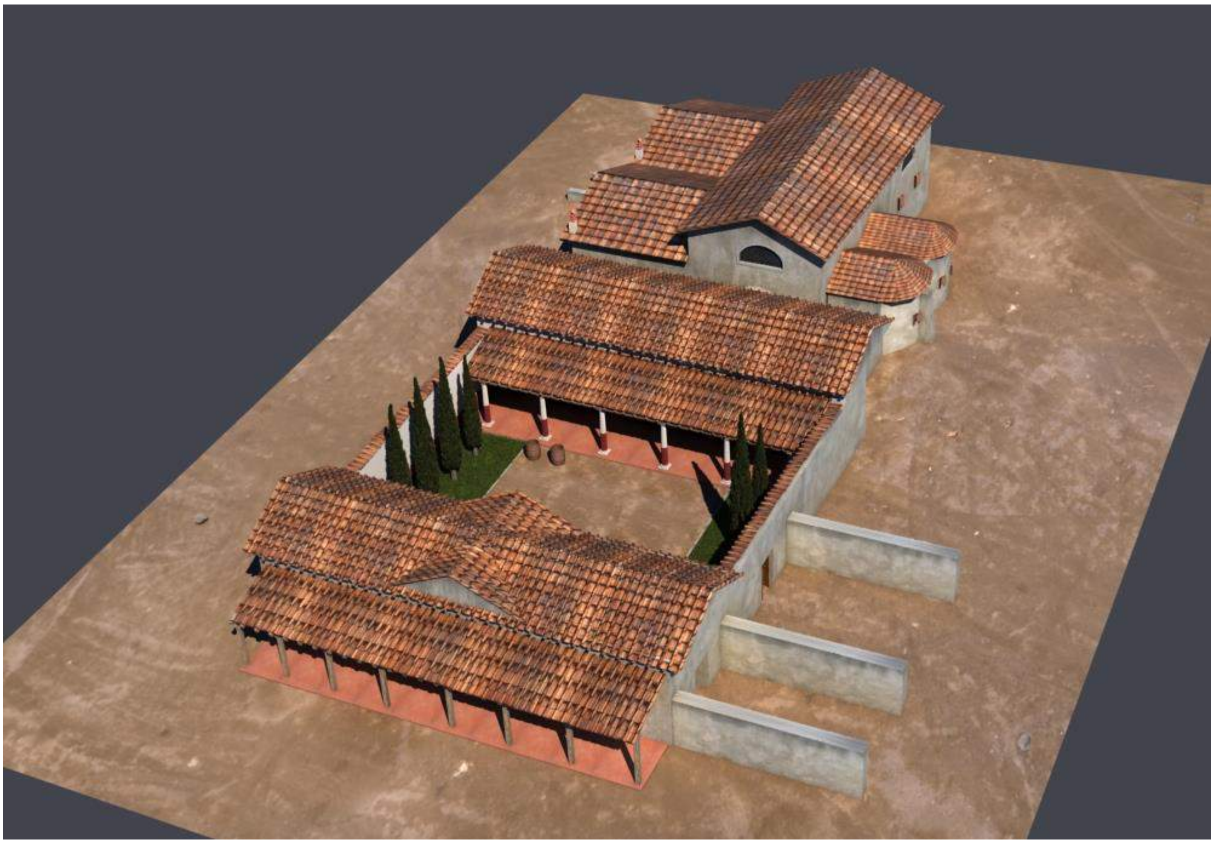


Fig. 45. VR reconstruction of the Roman baths at Százhalombatta, HU (image: 7reasons).

VR-reconstructions were uploaded for each pilot site as 3D files in FBX format with embedded textures. Sites of Sacidava, Iža, Százhalombatta and Vidin have also panoramic renders used for online and in app presentation (Fig. 45 and 46).

Sites of Zeiselmauer and Kopačevo have detailly 3D scanned FBX models with embedded textures. These 3D models are presented online through the platform Sketchfab (https://sketchfab.com/livingdanubelimes). LBI ArchPro also supported the development of a separate VR reconstructions app "Living Danube Limes VR" which is available on the Google Play app store (https://play.google.com/store/apps/details?id=com.sreasons.livingdanubelimes&gl=AT).

Fig. 46. VR reconstruction of the Roman camp at Iža, SK (image: 7reasons).

Project video documentation

A main objective of the project is the connection of the Danube Region by creating awareness for the value of its common Roman heritage. The dissemination of the project, its core topics and results to respective stakeholder groups has played a vital part in this endeavour throughout the project's running time.

LBI ArchPro has profound expertise in science dissemination including the production of TV documentaries and educational videos, which has been a priority of the Institute's research program for the past seven years. In the framework of the project, an extensive amount of high-quality video footage was acquired during the geophysical surveys at the pilot sites and the Austrian leg of the connecting cruise by LBI ArchPro media expert Gerhard Stüttler. In the concluding project period, the LBI ArchPro was thus assigned with the task of creating the final project video documentation of the project that fully, engagingly, and comprehensibly presents the scope of the project and the unifying potential of the EU Danube Transnational programmes.

Together with lead partner a concept was drafted identifying the main project topics to be featured in the video: general information on project and the Danube Limes, archaeology, geophysical prospection of pilot sites, VR-reconstructions & app, shipbuilding/reconstruction, connecting cruise, visibility measures, cultural heritage protection, cultural routes and tourism, the Danube Limes on the UNESCO World Heritage List.

A variety of activities such as living history events, conferences, workshops, public relations, a project app, and the connecting cruise of the Danuvina Alacris were implemented to reach a wide audience in the project. During several of these events extensive image footage was acquired by the project partners documenting progress and impact of the project over its duration of 2,5 years. Video footage was shared by all project partners and screened by LBI ArchPro to provide for a video as diverse and informative as possible, in which all partner countries are represented. The material covered various aspects of the projects e.g., the connecting cruise, shipbuilding, national events, museums, pilot site visits, geophysical surveys.

During the Austrian leg of the connecting cruise – from Tulln to the Slovakian border – Gerhard Stüttler shot exclusive video content documenting the Danuvina Alacris and its crew's journey from Tulln at the Römerfest on the 31st of July down to Bad Deutsch Altenburg (Fig. 47), where the ship crossed the Austrian-Slovakian border on the 5th of August 2022.

Fig. 47. Gerhard Stüttler filming during connecting cruise of the Danuvina Alacris in Klosterneuburg, AT.

Short statements of selected project partners were filmed that lead through the project video discussing core topics, benefits and perspectives, opportunities, and challenges in the project. For the interview locations, Roman sites were chosen to create an appropriate background in the video, e.g., Roman sites in Sofia (BG), the ancient amphitheater of Roman Carnuntum, the Roman watchtower in St. Johann im Mauerthale and the Roman fort of Mautern-Favianis in Austria (Fig. 48).

Fig. 48. Filming interviews with the Slovak project partner representative and Wolfgang Neubauer in Carnuntum, AT (left) and with the representative of the Bulgarian project partners (University of Architecture, Bucarest) in Sofia, BG (right).

The final 20-minute video included a professional voice-over and English subtitles and was uploaded on the project's YouTube-channel (https://www.youtube.com/@livingdanubelimes5610).

Popular science publication of project results

LBI ArchPro project staff wrote a scientific article focussing on methodology and results of the archaeological geophysical prospection surveys at the project pilot sites. The content was prepared for further dissemination in a special edition on the Danube Limes of the popular science magazine "Archäologie in Deutschland". A map was created in ArcGIS in consultation with the lead partner University of Continuing Education Krems (Fig. 49).

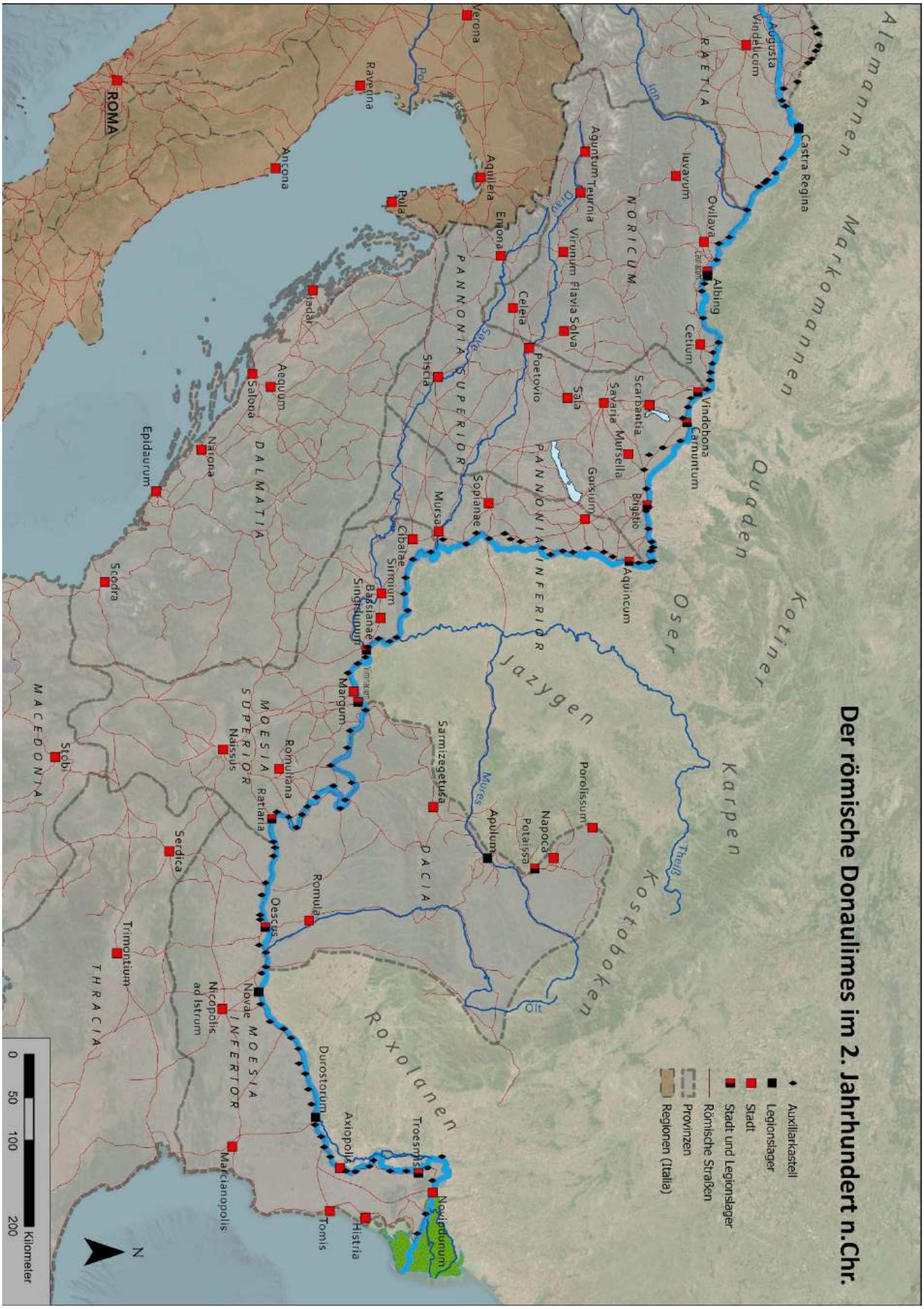


Fig. 49. Map of the Roman Danube Limes as published in the special edition of "Archäologie in Deutschland" (ArcGIS map: Matthias Kucera).

11.2 Kuelap

Short description of project: Safeguarding an endangered world heritage site using digital documentation techniques

Short description of site: Pre-Columbian site in Peru, main site of the Chachapoya (Warriors of the clouds) in Kuelap

Datasets: UAV based ALS; TLS; IBM

Keywords: novel digitization methods; large-scale remote sensing survey; remote sensing in challenging and remote environments; survey strategy

Benefits: safeguarding of and raising awareness for world cultural heritage (UNESCO tentative list); non-invasive investigation of archaeological sites; close collaboration with national and international academic institutions, governmental bodies, and world heritage management organisations

Introduction - the site

Kuelap is one of the greatest ancient monuments in the Americas - and one of the most endangered. The fortress sits picturesquely 3000 m above sea level on a mountain ridge of the Andes in northern Peru. It was the political center of the Chachapoya, a pre-Columbian culture that existed from about 900 to 1400 AD. In its heyday, the fortified settlement with city-like structures covered nearly 6 hectares over a length of 650m and a maximum width of 150m and had up to 5000 inhabitants living in hundreds of round stone houses (Fig. 50). The imposing enclosing wall was up to 20 meters high and was made of large limestone blocks. For a long time, Kuelap has been a major tourist attraction in Peru, and since 2019 it has been on the tentative list for inclusion as a UNESCO World Heritage Site, along with the Chachapoyas sites in Peru's Utcubamba Valley.

Fig. 50. View from the top of the Kuelap fortress to the South. In front a typical circular house structure of the Chachapoyas.

In 2019, LBI ArchPro was invited to conduct several TLS surveys in the area of the former Chachapoya culture in cooperation with the Brown University for the first time. In the spring of 2022, Kuelap suffered massive damage from heavy rains in the Amazon, which led to the collapse of parts of the fortress's perimeter wall and its closure to the public. The acute threat to the cultural heritage prompted UNESCO and the Peruvian Ministry of Culture to immediately contact the LBI ArchPro research team. Initiated and managed by the PUCP Lima (Catholic university of Lima/Peru) an international team of geodetic surveyors, architects, archaeologists, engineers, geophysicists cooperated with the LBI ArchPro, which became a part of this team.

The investigations at Kuelap attracted considerable attention from national and international heritage management and conservation institutions. Peruvian Minister of Culture Betssy Betzabet Chavez Chino, as well as delegates from UNESCO and the World Monuments Fund (WMF), which placed Kuelap on its watch list in 2004 due to its continued deterioration, visited the site during LBI ArchPro's research (Fig. 51) and saw in person that the current measures are guiding further decisions on sustainable monitoring strategies for the endangered heritage site and providing a foundation for virtual preservation and accessibility for future generations.

Fig. 51. Matthias Kucera (LBI ArchPro) explaining TLS datasets to the Peruvian Minister of Culture and delegates of the UNESCO and WMF.

Fieldwork campaign 2022

At the end of September 2022, the LBI ArchPro team (Matthias Kucera, Gerhard Stüttler) traveled to Peru to record the site three-dimensionally using various remote sensing methods during a two-week field mission and being part of the international team hosted by the PUCP Lima. Other members of this international team are the University of Wisconsin-Madison, Drexel University, Brown University (Boston), the University of Vienna and the UNESCO itself.

During the fieldwork campaign various methods have been applied and combined to record the status of the site in 3D. Methods include Terrestrial Laserscanning (TLS), Airborne Laserscanning (ALS), ground based and airborne Image based Modeling (IBM). Additionally, images in thermal and infrared band were captured for selected areas. Due to the location of the site on a hilltop the combination of terrestrial and airborne surveys was necessary as some parts of the site could not be recorded ground based only, due to steep cliffs in the North-Western part of the fortification. In 2019, a TLS survey had been carried out covering the walls from the most southern part along access 1 and access 3 (Fig. 52). By chance the area of the recent collapse was thus recorded. These data are available and are an important basis for further information and analysis of the situation.

Fig. 52. TLS survey at Kuelap 2019 (VZ2000 RIEGL LMS, photo: P.VanValkenburgh)

Home based tasks - processing, integration and interpretation

Besides the challenging data acquisition carried out by the LBI ArchPro in 2022 and 2019 respectively the processing, integration, and interpretation of various datasets from the LBI ArchPro's and third-party surveys are within the focus of investigations.

All these aspects foster a consequent application within the LBI ArchPro's research program, namely 3D data capturing and geographic referencing in remote and challenging areas, the integration of different 3D acquisition techniques and the establishment of standardized routines.

Specification of equipment

The following description of the instrumentation includes specifications of the equipment used in both surveys carried out by the LBI ArchPro during the survey in 2019 and 2022.

Terrestrial Laserscanning (TLS)

Fig. 53. TLS survey at Kuelap 2022 (VZ400i RIEGL LMS).

Laserscanner VZ2000 RIEGL LMS (2019), no camera attached

- Time off flight measurement
- Full wave form analysis
- Laser Pulse Repetition Rate: 50 kHz – 1 MHz
- Effective Measurement Rate: 21000 – 396000 meas./sec
- On board IMU and GNSS
- Accuracy: 8 mm (1σ at 150 m distance)
- Precision: 5 mm (1σ at 150 m distance)

Laserscanner VZ400i RIEGL LMS (2022), with camera attached (Fig. 53)

- Time off flight measurement
- Full wave form analysis
- Laser Pulse Repetition Rate: 100 kHz – 1,2 MHz
- Effective Measurement Rate: 42000 – 500000 meas./sec
- On board IMU and GNSS
- Accuracy: 5 mm (1σ at 150 m distance)
- Precision: 3 mm (1σ at 150 m distance)
- On board registration

Airborne Laserscanning (Visualskies)

Zenmuse L1 DJI

- Carried by Matrice 300 RTK (DJI)
- Effective Measurement Rate: 240000 - 480000 pts/sec
- Precision: 3cm (1 σ at 100 m distance)

Image based Modelling

For the collection of airborne IBM data three different systems were used. A Mavic Pro 2, Mavic Pro 3 and a Matrice 300 RTK with Zenmuse P1 sensor.

Mavic Pro 2

- RGB camera
- Sensor: 1”CMOS (20 Mio. Pixel)
- Lenses: 35mm Format equivalent: 28mm

Zenmuse P1

- Sensor: Fullframe (35,9 x 24 mm)
- 45 Megapixel
- Aperture: f2.8 – f16

Survey strategy

For the most complete 3D recording of the site a combination of TLS, ALS and airborne IBM was chosen. It was also the aim to compare the results of the different used sensors and methodologies to gain a basis for further decisions of ongoing monitoring strategies of the site.

TLS

In general, every TLS survey consists of several scan positions. To cover the complete surface of a specific object it is necessary to place the scanner at different locations to oversee most of the object. For areas and surfaces where this is not possible (e.g., rooftops) additional data can be added (ALS, IBM, etc.). All scan positions must be aligned to each other. For this purpose, different methods can be chosen. A traditional way to align e.g., two scan positions is to use control points, which are visible in both scans. When these control points are also recorded by a geodetic survey, the whole scanning project is also located within a given coordinate system. In this respect a scanning project consist of at least three different coordinate systems: (1) the coordinate system of each single scan position according to the orientation of the scanner, (2) a project coordinate system defining position and orientation of all scan positions and (3) a global coordinate system, which reflects the geographical coordinates of applied control points. In any case the resulting data is scaled automatically within the precision of the operated equipment in contrary to IBM data, where accurate scaling is only enabled by the use of control points.

Whereas the use of control points for the alignment of different scan positions guarantees best matching results, the practicability during a survey is reduced, when numerous control points must be placed and recorded by a geodetic survey, too (Fig. 54). Another option is the alignment of different scan positions according to the recorded geometry. Geometric objects such as reference planes are extracted from every scan and matched. For fast computing of the matching parameters a first estimation of location and orientation of each scan position is crucial. For this purpose, the VZ400i laserscanner has an onboard IMU and GNSS antenna. The system can be even operated in RTK mode, which safeguards a position accuracy of less than 2 – 3 cm. Additionally, the scanner tracks its movement for at least twenty seconds, which enables the calculation of a trajectory between single scan positions, i.e., as soon as the scanner is moved for less than twenty seconds between two scan positions the next location can be derived from the IMU data. In this case a GNSS signal is not necessary, which enables also surveying in areas with no satellite connection (e.g., mines, caves, buildings…). For absolute geographical positioning only a small set of control points can be used, ideally placed at several locations scattered in the survey area. For better control during the data collection process the VZ400i is capable of onboard registration of scan positions. The operator is ensured about the progress of the project in real time nearly.

The site of Kuelap might seem ideal for geometry-based alignment of scan positions as a lot of walls and clearly defined surfaces exist. On the other hand, some parts of the fortress are covered with vegetation (high grass, bush, trees), which causes noise in the data. Nevertheless, based on the experience of the 2019 survey and after analyzing the results after the first days in field proved that geometric alignment, which is complemented by a set of control points for georeferencing, will be sufficient to guarantee an accurate survey. An overall relative accuracy according to the precision of the applied system (3mm at 150m distance) must be achievable.

Fig. 54. The placement and recording of control points in the rain forest is a challenging task. Parker VanValkenbourgh during field work in 2019.

During the first days in field a focus was set on the recording of the external walls. It was the further aim to record all accessible areas also inside the fortress presupposed good weather conditions.

IBM

During the survey of 2022 a focus was set on the application of IBM based on UAVs. Two Mavic Pro 3 were available to record most of the site, especially the areas, which were not accessible ground based. Namely the NW cliffs were recorded using this approach. Two buildings (*el tintero, el torreón*) required to be recorded airborne to also cover their top. Access with a terrestrial laser scanner would have been too dangerous.

For the latter georeferencing and scaling of the data several control points have been placed along the walls. These control points have been recorded through a geodetic survey. In addition, control points can be derived from TLS datasets in order to guarantee even better accuracy when integrating the datasets.

As it is presumed that vegetation plays a key role for understanding the structural changes of the site IR photography has been applied at some parts of the perimeter walls, namely south of the collapsed area. In this area a lot of control points have been placed, which should enable high quality comparison of all datasets.

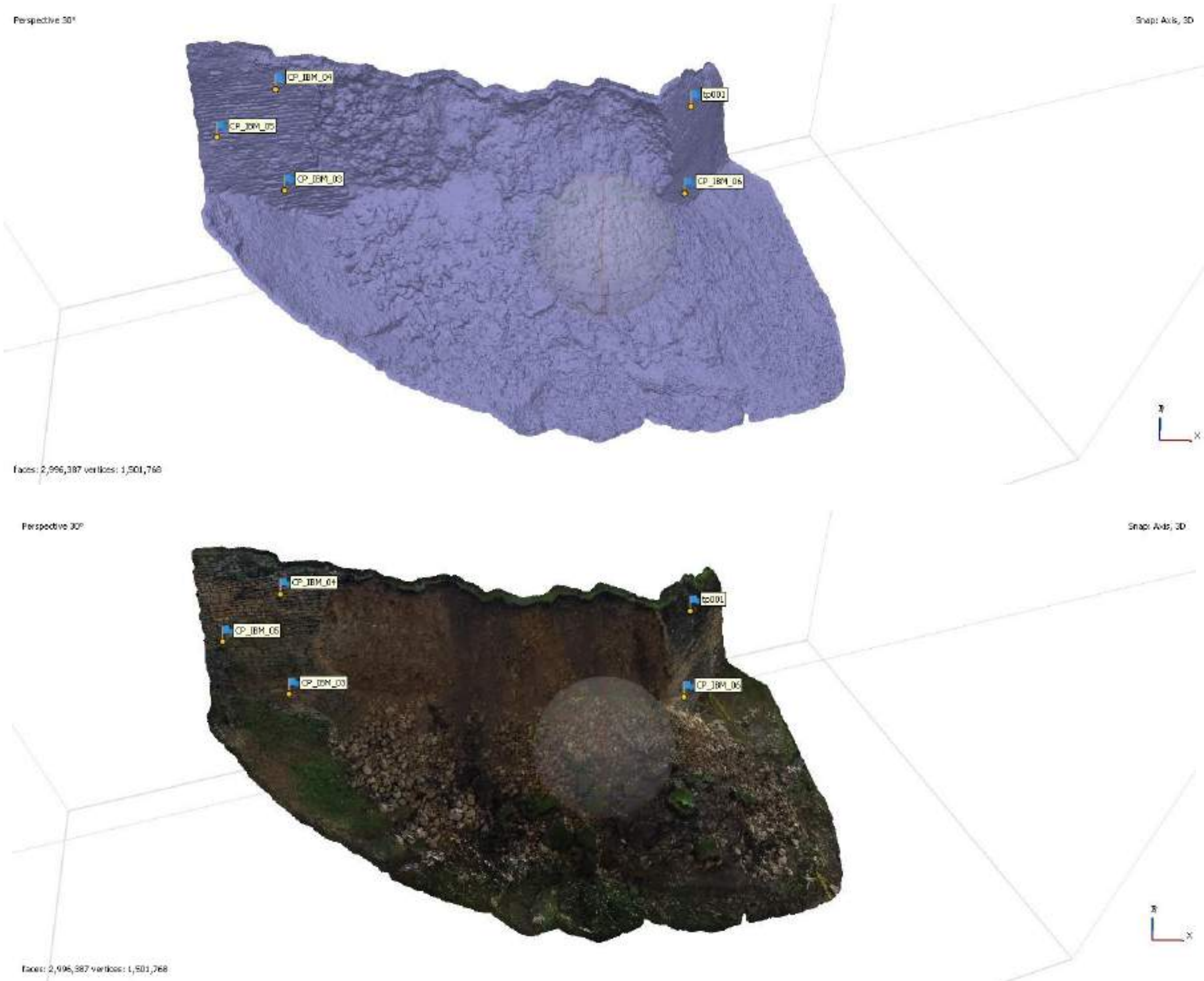


Fig. 55. IBM model of collapsed wall area, control points derived from TLS survey 2019 (above: untextured; below: coloured).

ALS

In cooperation with National Geographic and their subcontracted company *Visualskies* an ALS survey has been carried out using a DJI Matrice 300 equipped with a Zenmuse L1-sensor. Although the precision and accuracy of this system is not comparable to the LBI ArchPro´s RIEGL VUX-SYS sensor, the systems bear some advantages for operating in remote areas. The application of the system even at high altitude (RICOPTER is limited to approx. 3000m ASL, which would have meant flying at its limits) is straight forward and stable. A disadvantage for scientific purposes is, that also the processing follows a “black box” pipeline. Nevertheless, areas which were not accessible were recorded successfully resulting in a 3D model of the whole site including the whole cliff front towards an area (*la baretta*) where graves in the cliffs are located (Fig. 56). The strength of the DJI system is the recording of data in a very easy (and stable) way. Unfortunately, no control points have been placed, which will make the manual extraction of distinct control points from the TLS data necessary.

The resulting point density of the model is well above 400 points/m^2 including vegetation. The data is noisier if compared with TLS, which represents the observed accuracy of 2 to 4 cm.

Fig. 56. 3D model of Kuelap, ALS (L1 sensor; image: Visualskies).

Results of surveys

Within 7 days in the field 1146 scan positions were recorded, which equals 23 billion points roughly (Fig. 57 and 58). An average point raster of less than 3 mm can be expected. It was possible to cover most of the site in this resolution including some of the surrounding area. As presumed, only the western fortification walls south of *el torreón* and along *pueblo alto* were recorded sparsely due to the steep cliffs, where no ground based physical access was securely possible. These areas were also recorded using ALS (L1 sensor) and airborne IBM. Most important was the implementation of a geodetic survey, during which most of the placed control points were recorded.

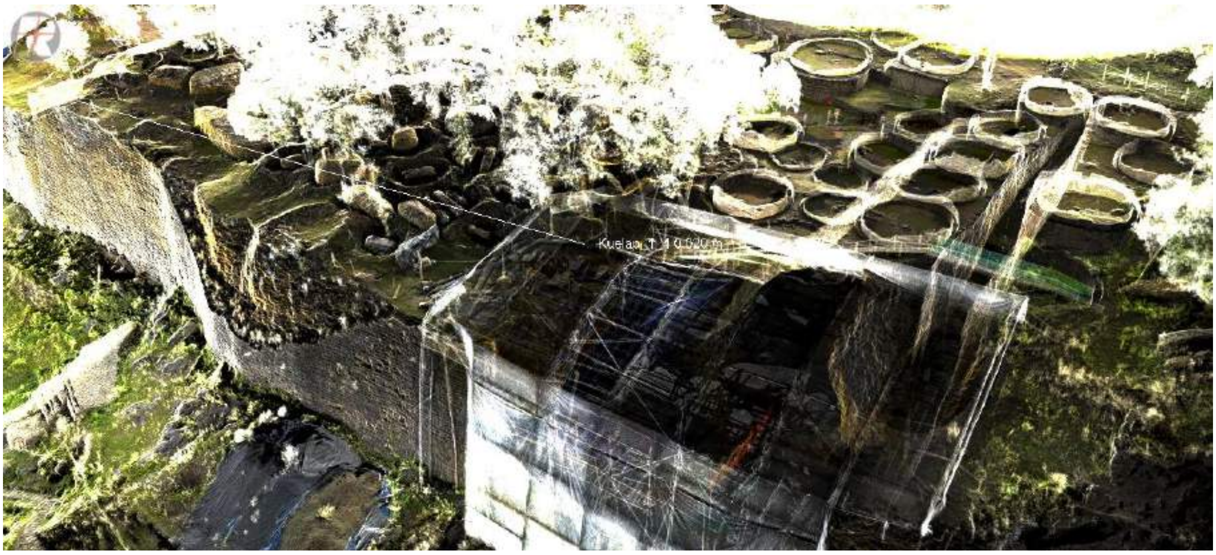


Fig. 57. TLS data collected in 2022 showing the area around access 1.

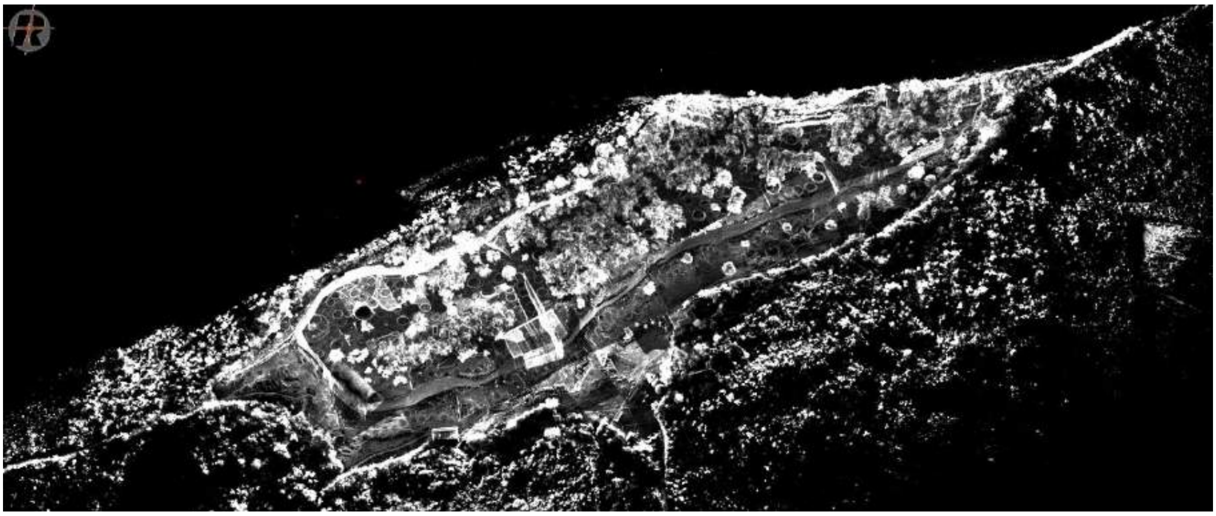


Fig. 58. Point cloud of the whole site (TLS, VZ400i, 1146 scan positions, 5 billion points).

Further strategy

All data including TLS, ALS and IBM has to be processed and aligned (georeferenced) according to the control points recorded by the geodetic survey. Data must be cleaned and filtered (e.g., vegetation cover must be removed virtually). After that, several tasks will be carried out:

- Comparison of the TLS data from 2019 and 2022 to investigate possible mass movements of the wall.
- Combination of all data (IBM, ALS, TLS) to produce a complete, colored 3D model of the site.
- Comparison of the quality of IBM and TLS data.
- Development of a monitoring strategy of the site, either based on TLS or IBM.
- Suggestion of further steps for monitoring and safeguarding of the cultural heritage site of Kuelap.
- Display of the data in virtual reality (public viewer).
- Guarantee virtual accessibility of the site.

Processing

The main steps of this procedure include the alignment of all scan positions (TLS), the generation of 3D models according to IBM workflow, the filtering of the resulting point clouds and the georeferencing according to the geodetic surveys. It turned out that the latter is the most crucial and challenging part. In comparing the different datasets from all time periods, it turned out, that the TLS data of 2022 in combination with the geodetic survey guarantee most accurate results and comparability. These data must be seen as the backbone for all previous and future surveys.

Including the available data from third-party surveys, the dataset at hand holds important information regarding site development, archaeological studies and multidisciplinary interpretations and analyses. Table 2 gives a brief overview of all available datasets (3D data capturing) and their current processing status stored at the LBI ArchPro.

Method	Year	Carried out by	status
TLS	2019	LBI ArchPro	Processed and georeferenced
TLS	2022	LBI ArchPro	Processed and georeferenced
IBM – terrestrial	2019	LBI ArchPro	Processed
IBM - aerial	2019	LBI ArchPro/ third party	available
IBM - terrestrial	2022	LBI ArchPro	Processed (IR)
IBM - aerial	2022	LBI ArchPro/third party	processed
IBM – aerial 1	2022	Third party (after collapse)	Processed and georeferenced
IBM – aerial 2	2022	Third party	processed
IBM - aerial	2018	Third party	processed
IBM - aerial	2019	Third party	processed
ALS (DJI L1)	2022	LBI ArchPro/ third party	processed
ALS (Velodyne)	2018	Third party	processed

Table 2. Available datasets of Kuelap surveys 2018-2022.

Fig. 59. LBI ArchPro staff members Matthias Kucera and Gerhard Stüttler during the survey at Kuelap in 2022.

11.3 INDIGO

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

LBI ArchPro staff members Jona Schlegel and Geert Verhoeven (PI) are allocated almost entirely to the project for its duration. The project addresses several key topics of the LBI ArchPro research programme such as data recording and processing, data management, spatio-temporal analysis, and dissemination & awareness all of which are covered in the following report.

Conducted and current research

Pushing the boundaries of the status quo in inventorying and understanding extensive graffiti-scapes is a major goal of project INDIGO (IN-ventory and Disseminate G-raffiti along the d-O-naukanal). This two-year project, which launched in September 2021 through funding of the Heritage Science Austrian programme of the Austrian Academy of Sciences (ÖAW), aims to build the basis to systematically document, monitor, disseminate, and analyse a large part of the graffiti-scape along Vienna's central water channel *Donaukanal* (Eng. Danube Canal) in the next decade.

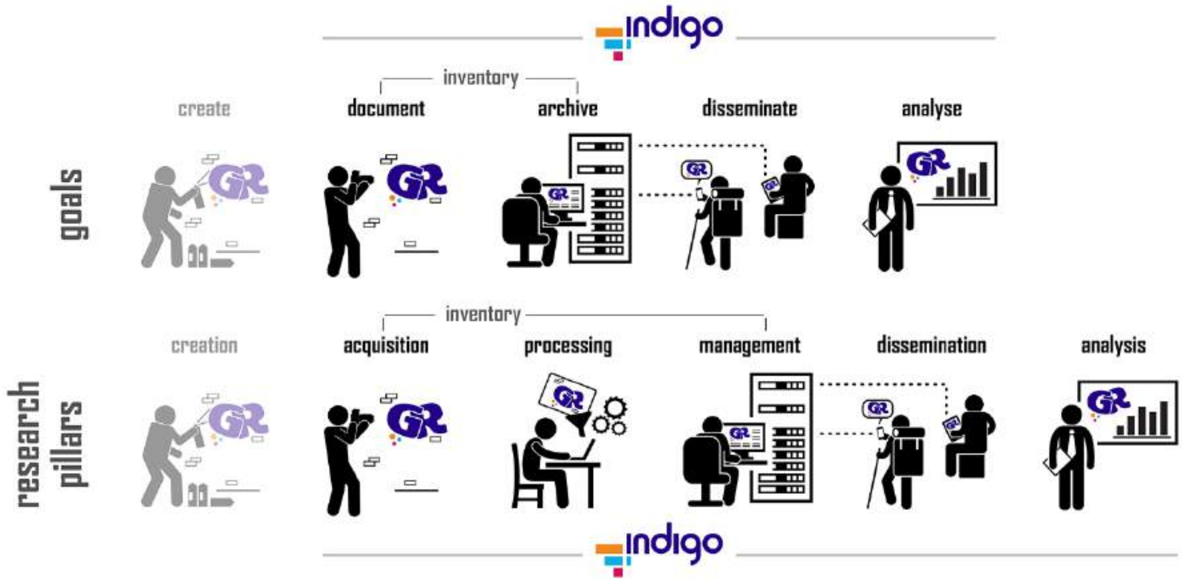


Fig. 60. A graphical overview of INDIGO's goals and research pillars. Although everything starts with producing a graffito, creating graffiti falls outside the scope of project INDIGO.

In doing so, INDIGO wants to digitally preserve this unique, complex, short-lived and socially relevant form of cultural heritage, as such leveraging its potential to disclose new socio-political-cultural research questions and graffiti-specific insights. To accomplish those aims, INDIGO is structured around five research pillars: 1) acquisition, 2) processing, 3) management, 4) dissemination and 5) analysis (graphical overview presented in Figure 60). Each of these pillars is covered by one or more Work Packages (WP) as outlined below.

Hard- and software acquisition

During the first project months, considerable time has been invested into researching and purchasing the most appropriate hard- and software at the best possible price. Instead of two portable X-Rite Ci60 spectrophotometers as previously intended in the project proposal, a more accurate Konica Minolta

CM-26d was purchased. This instrument will become very important during the second project year when INDIGO needs to assess the colourimetric workflow and develop a graffiti-specific colour reference chart.

Photography

Taking photographs is INDIGO's main activity. The original project plan mentioned four so-called 'total coverage' surveys besides weekly or bi-weekly follow-up photography tours.

At least once per week, one of the three photographers goes out to document new graffiti. These photographers have a pool of various hardware available: two identical imaging systems, two ColorChecker Passport Photo 2 colour reference targets by X-Rite (now produced by Calibrite), two Solmeta GMAX GNSS (Global Navigation Satellite System) receivers, two Sekonic C-7000 SPECTROMASTER spectrometers and two Samsung Galaxy Tab A7 Lite tablets (see Fig. 11). All devices of the same type are labelled "A" and "B" to distinguish them. Device B is always set up identically to device A. For example, the tablets run the same apps, and all settings of both spectrometers are identical.

INDIGO relies on two Nikon NIKKOR Z 20mm f/1.8 S lenses paired with a full-frame mirrorless Nikon Z7 II camera generating 45-megapixel photos. The Solmeta GNSS receiver is attached to the camera's hot shoe and directly writes geographical coordinates into the photo's Exif metadata. Both cameras feature the same settings. This not only enforces identical results (from a technical point of view) across imaging systems; it also ensures that the camera-related photo properties are appropriate for INDIGO's colourimetric and geometric processing pipelines.

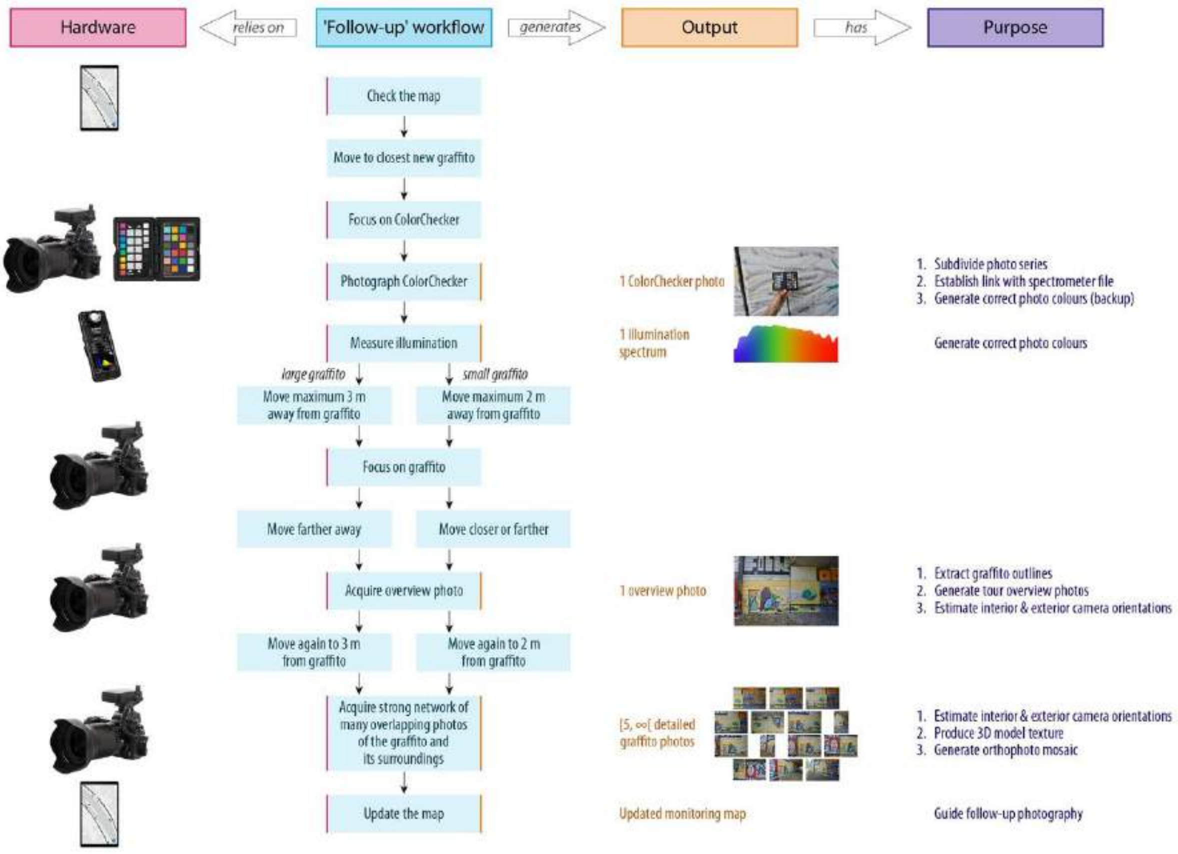
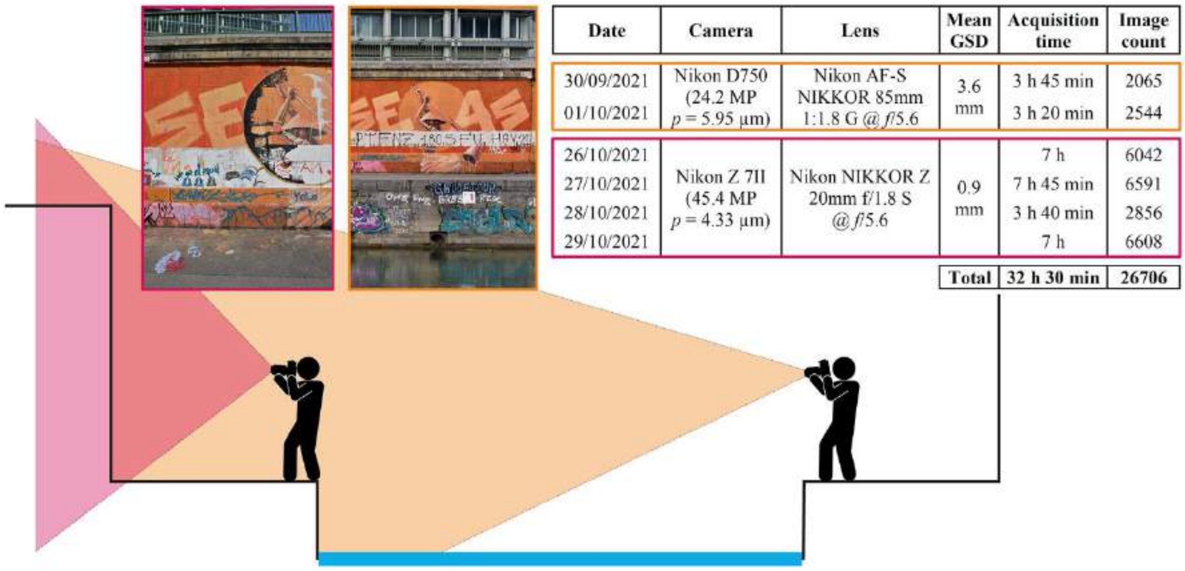


Fig. 11. Follow-up photography workflow for a new graffito. The illustration indicates the hardware needed and the purpose(s) of the generated outputs.

During the first year, the data acquisition and graffiti monitoring workflows (Fig. 11) witnessed several significant and minor changes. For example, no spectrometer was available at the beginning, and the order of acquiring specific photos (like the overview photo or the photo of the ColorChecker target) was different. Even though there currently is a well-defined data acquisition workflow, minor mistakes still occur now and then.

In addition to this follow-up photography, four moments for a total photographic coverage had been scheduled (September/October 2021 and 2022, March/April 2022 and 2023). The first of those coverages took place in October 2021. Spread over six days, a zone slightly exceeding INDIGO's entire research area (containing 13 km of graffitied surfaces – Fig. 63) has been photographed in detail. In the first two days, the channel's embankments were photographed at a time when the water level was shallow. Photos from the left bank's wall were captured from the channel's right bank and vice versa (everything related to this acquisition is depicted in orange in Fig.62). During the last four days, all other surfaces were photographed (indicated with pink in Figure 62), generating 26.7k photographs altogether.



Date	Camera	Lens	Mean GSD	Acquisition time	Image count
30/09/2021	Nikon D750 (24.2 MP $p = 5.95$ µm)	Nikon AF-S NIKKOR 85mm 1:1.8 G @ $f/5.6$	3.6 mm	3 h 45 min	2065
01/10/2021				3 h 20 min	2544
26/10/2021	Nikon Z 7II (45.4 MP $p = 4.33$ µm)	Nikon NIKKOR Z 20mm f/1.8 S @ $f/5.6$	0.9 mm	7 h	6042
27/10/2021				7 h 45 min	6591
28/10/2021				3 h 40 min	2856
29/10/2021				7 h	6608
			Total	32 h 30 min	26706

Fig.62. The first total coverage photographic survey took place during two and four consecutive days at the start and end of October 2021, respectively. Both survey moments also utilized a different camera setup and acquisition strategy. This illustration uses orange (for the first two days) and pink (for the last four days) to indicate all the relevant data, the photographer's position and a sample photo of both photographic campaigns.

These photographs serve three essential purposes:

- First, a digital 3D model that encodes the geometry of all solid surfaces along the Donaukanal can be computed from them (see "Geometric backbone").
- Second, these photos create a graffiti status quo. They constitute a complete record of the graffiti-scape at a particular moment, thus effectively establishing INDIGO's starting point for tracking change in the graffiti-scape via follow-up photography.
- Third, those data enable the efficient processing of new graffiti photographs. Within INDIGO, all graffiti photos acquired during the follow-up photography are processed into two end-products: geometrically corrected orthophotos and textures for a 3D surface model. The production of both products can be considerably sped up with knowledge about the

camera's exact location and angular rotation when acquiring each of these total coverage photos.

A new total coverage survey took place at the end of October 2022. The resulting 43k photographs served two primary purposes: 1) to provide additional photographs to create a complete 3D surface model of the Donaukanal, and 2) to establish a new status quo for the second project year. A third total coverage survey is not planned because of how the change detection approach will be implemented. In contrast, the (bi)weekly follow-up photography continues in 2023 with the same intensity as in 2022.

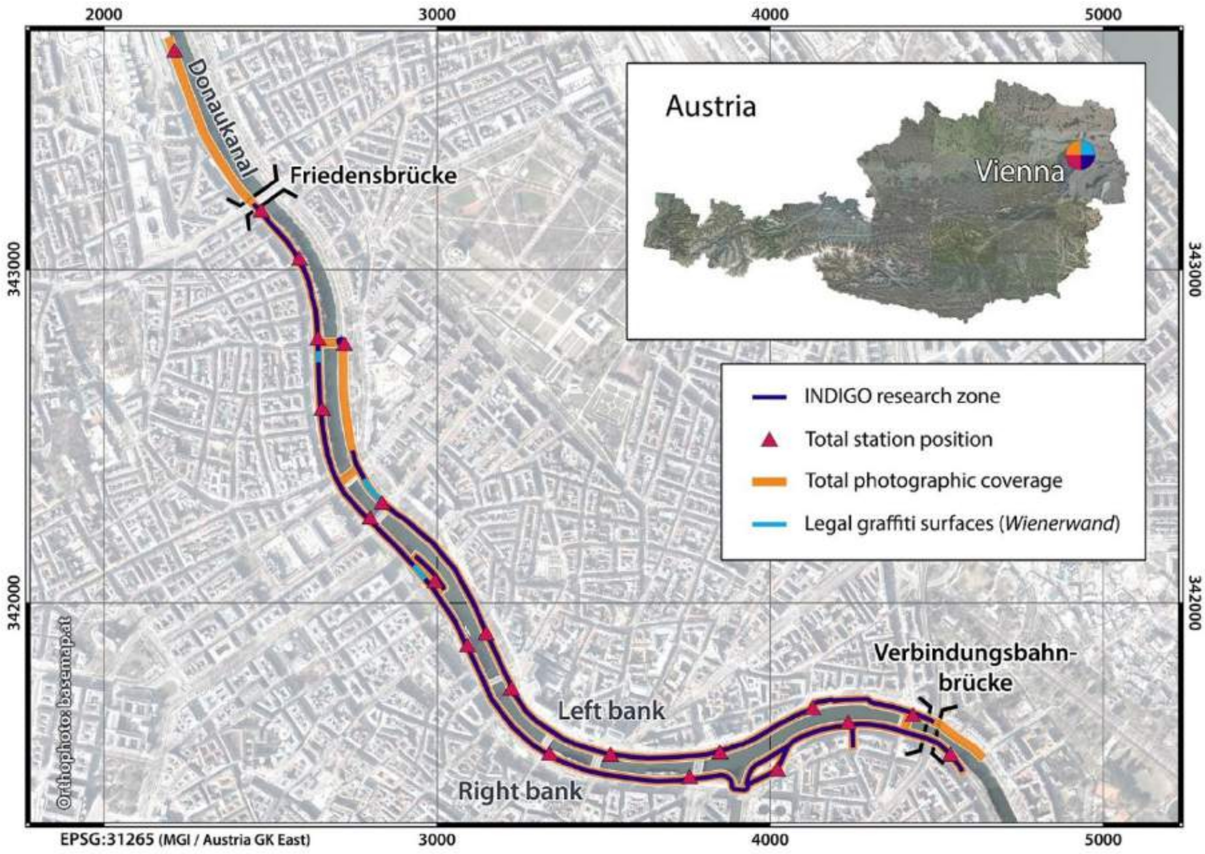


Fig. 63. All urban surfaces covered by project INDIGO (and the limited number of legal graffiti surfaces in this area). The illustration also depicts INDIGO's 2021 total coverage zone and the positions from where graffiti-scape points were measured (see WP 7).

After much research on the complex problem of image copyright and all aspects concerning legal data sharing , INDIGO adopted the general and safe "In Copyright" statement for all photographs. This statement from rightsstatements.org clarifies that each photograph "is protected by copyright and/or related rights. You are free to use this Item in any way that is permitted by the copyright and related rights legislation that applies to your use. For other uses you need to obtain permission from the rights-holder(s)." The IPTC (International Press Telecommunications Council) image metadata of every INDIGO photograph mentions all this necessary rights info.

Since the beginning of INDIGO, it became clear that it would be crucial to consider and address moral and ethical questions (e.g., how to deal with hateful, subversive, potentially illegal or other sensitive content). As a result, INDIGO consulted TU Vienna's research ethics coordination for counselling. In a meeting with the Pilot Research Ethics Committee (Pilot REC), the project's ethical dimensions and potential strategies to tackle them were confidentially discussed and a statement was drawn up (https://projectindigo.eu/wp-content/uploads/2022/05/INDIGO_ethicsStatement.pdf).

GNSS/IMU

Currently, a Solmeta Geotagger GMAX is mounted on the camera. This unit uses the American GPS and Chinese Beidou satellite constellation to compute the camera's location with a precision of about 2.5 metres (at one standard deviation). This precision can be reached in ideal scenarios because the unit uses the correction signals broadcasted by the satellite-based augmentation system EGNOS (European Geostationary Navigation Overlay Service). The estimated geographical latitude, longitude, and altitude values are written into the Exif metadata of the RAW and JPEG files. These values are leveraged in the orthorectification workflow for computational speed improvements. However, acquiring more accurate coordinates for every camera station would be helpful.

The INDIGO team has developed a device to record the camera's exterior orientation. Built from commercially available but cost-effective components housed in a 3D printed case, this device also connects to the hot shoe on top of the camera. It receives a Real-Time Kinematic (RTK) GNSS correction from the Austrian EPOSA service (Echtzeit-Positionierung-Austria), for which the settings get wirelessly controlled from the tablet or any smartphone (Fig. 64). First tests have indicated the potential of this device to obtain centimetre-accurate coordinates and sufficiently correct rotation angles for each camera station.

INDIGO is very proud of this truly unique device. No other hardware solution offers this functionality out of the box. The most similar device on the market is the 3D ImageVector from REDcatch. However, handling the REDcatch device is more cumbersome due to its long cable and attached data logger. At the same time, the obtained camera rotation angles are much more inaccurate than those from INDIGO's device. At the start of 2023, two months are foreseen to intensively test the device, write a user manual and programme a small script to store the positional and rotational values as metadata, either in the image or in a separate file.

Fig. 64. The new RTK-enabled GNSS-IMU logging device (left and middle) with the interface controlling its settings (right).

3D Geometric backbone

INDIGO aims to document most new graffiti created along a large part of the Donaukanal via thousands of photographs that digitally encode the stratified graffiti-scape. Highly processed versions of these photographs will end up in a spatial database that feeds an online platform where users can freely and virtually visualise and query all graffiti records. To provide clean and relevant data for the spatial database and online platform, i) three-dimensional (3D) surface geometry of the Donaukanal, ii) photographs of the graffiti, and iii) auxiliary data must be acquired. The 3D digital surface is vital to remove the geometrical photo deformations. It is also the backbone onto which graffiti images will be mapped for display online.

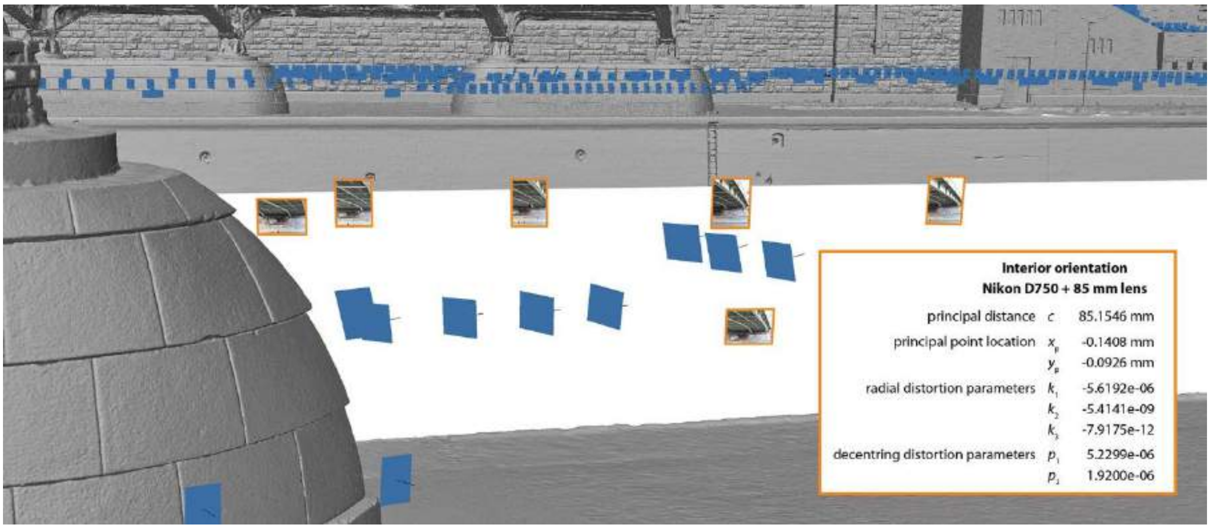


Fig. 65. A portion of the polymesh that digitally represents the solid surfaces along the Donaukanal. The blue rectangles visually represent the exterior orientations of the camera stations. At the camera stations featuring an orange outline, a photo was captured from the opposite bank with a Nikon D750 camera plus an 85 mm lens. Those photos are shown inside the orange strokes, while the lower right inset provides the parameters describing the interior orientation of this camera-lens combination.

In the first two 'total coverage' surveys, a zone slightly exceeding INDIGO's research area (Fig. 63) was photographed in October 2021, and in October 2022. Using techniques from the photogrammetric and computer vision fields (more specifically, Structure from Motion or SfM), it was possible to determine the camera's position and angular rotation for all acquired photos (Fig. 65). In addition to these so-called exterior camera orientations, the SfM algorithm also produces the camera's interior orientation parameters: a handful of variables that describe the camera's internal geometry (see Figure 65 for an example).

However, there is one problem with the approach mentioned above: the output of an SfM algorithm is expressed in an arbitrary coordinate reference system, meaning that the estimated positions and rotations of the thousands of camera stations are only equivalent to their real-world values up to a global scaling, rotation, and translation factor. The SfM output was embedded in a real-world coordinate reference system via a dense network of over 600 Graffiti-scape Points (GPs), measured during a multi-day total station surveying campaign (Fig. 66). These GPs are object/scene points that are well-identifiable in many photos (even when potentially sprayed over) and whose long-term positional stability can be assumed (Fig. 66, inset). Their coordinates were determined from one of the 21 total station locations that INDIGO established along the Donaukanal (Fig. 63). After indicating these 100s of GPs points in many thousands of photos, the SfM output could be accurately expressed in the MGI/Austria GK East coordinate reference system (EPSG:31256).

Fig. 66. Benjamin Wild operating the Leica Viva TS16 total station. The inset on the lower right displays three typical GPs.

With all cameras correctly oriented, it is possible to generate a continuous, digital 3D model that encodes the geometry of all solid surfaces along the Donaukanal. This is achievable via Multi-View Stereo (MVS), another photogrammetric computer vision technique. When given a set of detailed photos for which the image overlap is substantial, an MVS algorithm can produce a hole-free digital 3D surface representing fine geometrical features. Since this case meets both requirements, the well-known SfM-MVS software package Agisoft Metashape Professional could generate a preliminary, continuous 3D surface as a polymesh (Fig. 66) for both total coverage surveys. Since INDIGO's envisioned online platform should offer virtual walks along the Donaukanal, these digital 3D surface models will form its geometric backbone. Creating the final 3D surface meshes is a work-intensive task for which circa three months are scheduled in 2023.

Colourimetry

The documentation of cultural heritage typically focuses on the geometrical aspects and seldom the spectral dimensions of an artefact. INDIGO made it one of its central aims to generate colour-accurate photos from graffiti captured with standard digital cameras in varying outdoor illumination conditions. To enable this, one of the main intended deliverables was an open-source toolbox. This software was finished and made freely available at the end of August 2022. INDIGO's COlour Operations Library for Processing Images (COOLPI) is available from its GitHub repository. At the same time, an extensive user manual is available at https://graffitiprojectindigo.github.io/coolpi. A few more weeks in 2023 are needed to evaluate the software and combine its functionality with the geometrical processing pipeline.

A graffiti-specific colour reference chart was created to obtain higher colour fidelity when the colour reference target features graffiti-specific colours. Throughout the first project year, colour swatch books of all major spraycan brands were bought. These samples support the creation of a novel graffiti-specific reference target. The spectral reflectivity of every colour sample will be determined with INDIGO's Konica Minolta CM-26d spectrophotometer. Collecting all these spectral signatures yields, in turn, a spectral database specific for graffiti spray paint. Such a database does not exist yet. However, making it freely available could open new pathways for other researchers interested in the automated detection of graffiti (colours).

Orthorectification and texturing

The extensive digital 3D model with colour-accurate textures of the Donaukanal's graffiti-scape of INDIGO's envisioned online platform will allow users to view every graffito in its correct urban setting, both spatially and temporally. Because the 3D textures and 2D orthophotographs will be queryable via an underlying database, the platform can support *intra*- and *inter*-graffito visualisations and analyses, thus providing as much context as is technically feasible.

To deal with massive amounts of photos and create textures for the 3D mesh along with orthophotos, the team has developed the python-based software AUTOGRAF (AUTomated Orthorectification of GRAFfiti photos). AUTOGRAF is distributed via INDIGO's GitHub. This free tool is an add-on for the popular software Agisoft Metashape Professional. It leverages the SfM and MVS functionality of Metashape. Still, it adds much automation and a few new functions so that graffiti photos can automatically be transformed into distortion-free graffiti orthophotos and mesh textures.

Segmentation and annotation

To create a 2D orthophotograph and a texture patch for the 3D mesh, it is necessary to define the outer boundary of each graffito in real-world coordinates. The resulting 3D polygon is then the spatial entity that represents the graffito. In other words, all metadata are linked to this polygon. At the moment, this polygon is defined via an overview photo of the graffito (enabled via AUTOGRAF), but a more flexible and automated solution is needed. Flexible means that the processing pipeline should allow this segmentation to occur at any stage. For instance, after downloading all photos acquired during a follow-up tour, it is not unimaginable that 30 minutes are spent segmenting every new graffito from its environment in the overview photos. However, this means that the processing pipeline should store this 2D polygon and use it after the orthorectification stage to extract its 3D coordinates. Another possibility could be to segment automatically after the orthorectification stage. Suppose the latest orthophoto can be compared with an earlier orthophoto. In that case, a change detection procedure might yield this polygon in an automated way. Although graffito segmentation is thus currently possible, its exact implementation will also depend on the change detection procedure that is developed.

A similar problem concerns metadata annotation. The 3D texture patch and 2D orthophoto will have metadata about their processing parameters. In contrast, the final polygon (and the corresponding entry in the spatial database) must also store info on content, stylistic characteristics and temporality. Like the segmentation step, the exact stage of metadata entry is still undefined. Much information could be added to the images using photo cataloguing software such as Camera Bits' Photo Mechanic Plus or Photools' IMatch (both available in project INDIGO). These solutions would embed the necessary metadata in the image or a sidecar file (likely via an INDIGO-specific XMP namespace). This XMP metadata could then be read by OpenAtlas (INDIGO's database solution), but such functionality must be programmed. One could also add this information at a later stage directly in the database. The latter workflow has the advantage that no extra functions are needed, and that at the time of ingestion (typically a few days or weeks after photo acquisition), info on temporality (like the period a graffito was visible) might be known. However, any workflow is currently waiting for progress in the thesaurus.

Graffiti research is notorious for using a wide variety of unstandardised terms, which prevents analysis on a larger-than-local scale. For example, suppose database A labels a creation 'graffito', while database B considers the same work as 'street art'. In that case, cross-database queries would lead to partial results and conflicts. And even if multiple people enter data into OpenAtlas, the fact that they might be using different personal definitions for the same terms could render that database unusable. To avoid the inaccurate, biased or even impossible analysis that stems from too much terminological elasticity, project INDIGO decided to create a broad, graffiti-centric thesaurus of well-defined terms. These terms will be used during metadata annotation. Although much time has been invested in this thesaurus, it is still unfinished because developing a well-structured, semantically-sound thesaurus has proven much more challenging than anticipated.

Change detection

The initial idea of image change detection was related to the total coverage tours, of which the last three should help detect previously undocumented graffiti via automated change detection. However, as the initial monitoring strategy (finding new creations via Instagram or relying on visual memory when walking/biking along the channel) proved insufficient to spot minor graffiti, a new monitoring approach was born based on image change detection: two GoPro HERO10 action cameras are mounted on a camera bar. The bar connects to a handgrip, allowing the dual-camera construction to be handheld. Because the camera lenses point in approximately opposite directions, one can photograph nearly every surface above and below the walking/biking path by biking once on each side of the channel (Fig. 67).

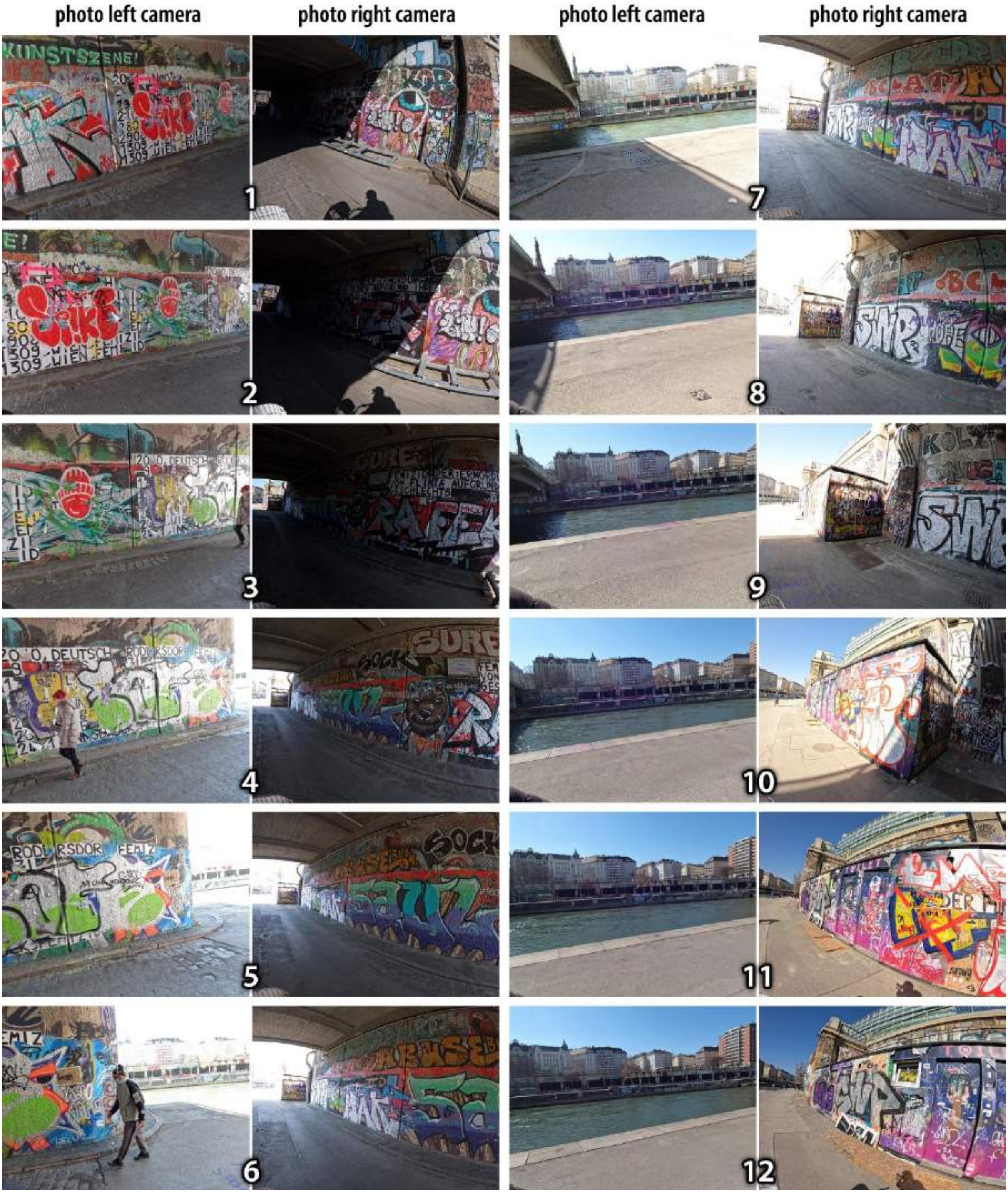
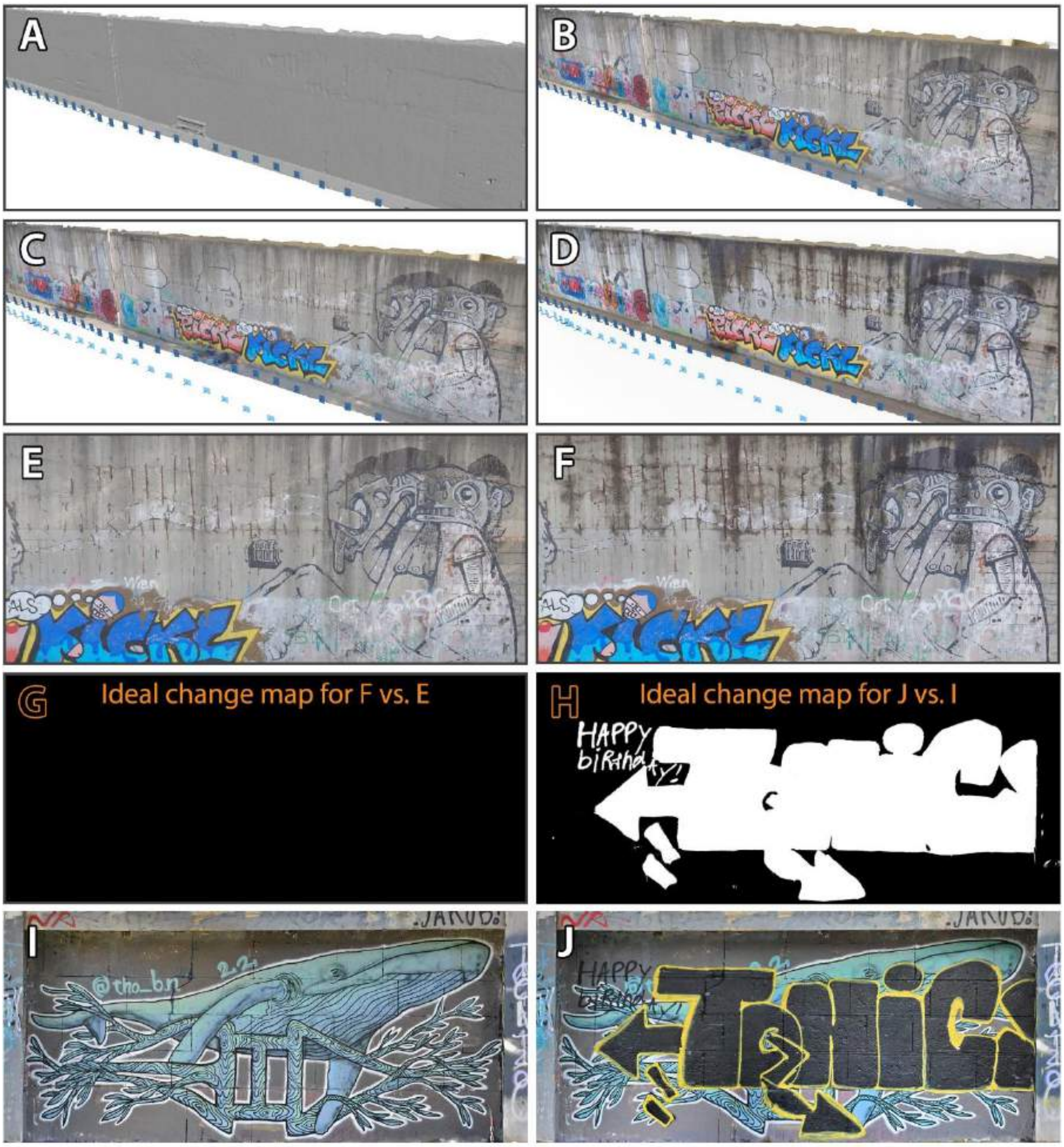


Fig. 67. A sequence of twelve left-right photographs acquired from the Donaukanal's left bank.

Using the previously mentioned SfM approach, the exact exterior orientation of each camera station is retrievable. Imagine a GoPro photo series acquired during a one-hour biking tour on Monday morning and correctly processed with SfM by Tuesday afternoon. At that point, one can compute a meshed 3D surface of these images using an MVS algorithm (Fig. 68A). Once the mesh is ready, it can be textured with the photographs (FigB). After a rainy night, a new GoPro photo series is collected on Wednesday morning. Because an incremental SfM approach can leverage the network of oriented Monday photos (i.e., the dark blue rectangles in Fig. 68C), the position and rotation of the newest camera stations (symbolised by the light blue rectangles in Fig 68C) are estimated by Wednesday evening.



Fig, 68. The sequence of insets A to D explain how two photo events could result in two pixel-perfect aligned textures (E and F), from which one could extract a change map. In this case, the change map (G) should be blank because all changes that occurred are unrelated to the graffiti. This is not the case for the scene changes between insets J and I. Here, inset H depicts the ideal change map. Both change maps were manually generated with Adobe Photoshop 2022.

At that stage, the mesh computed on Monday gets textured with the Wednesday photographs (Fig. 68D) so that two textures exist, partly displayed in Figure 68E and Figigure 68F. Ideally, these texture images are pixel-perfect aligned so one can look for differences between any two pixels at any location. In its most simple way, this last step could subtract the Monday texture from the Wednesday texture to yield a so-called change map or change image. Since this change map depicts any relevant difference that occurred in the graffiti-scape between Monday and Wednesday, it is a perfect guide for the follow-up photography tour on Thursday.

However, the hard part of this workflow is the change detection step. So far, none of the tested algorithms has proved capable of robustly computing change maps in a reasonable amount of time.

The challenges to this problem predominantly lie in the large pixel counts of the images and the different photo renderings of an unchanged scene. Let us consider the last issue. Photographing an invariant graffiti scene once in cloudy conditions and once in harsh sunlight will result in two photos that look different. Not only might the colours look distinct, but the sunlight will generate strong shadows that are absent in the other photograph. Although a human quickly understands that the graffiti-scape itself did not change, designing an algorithm robust to these graffiti-irrelevant photo differences has proven hard. The same problem occurs after a rain shower. The ideal change map (Fig. 68G) between Figure 68E and F is blank because the only scene variation between both photo events relates to rainwater running down the concrete (Fig. 68D and F). These challenges notwithstanding, INDIGO will continue to invest time in this change detection approach – mainly focusing on more uncomplicated cases like Figure 68H – because it could prove helpful for many heritage monitoring projects. To achieve substantial progress in this WP, INDIGO actively looks worldwide for students in image processing and computer vision that could write their Master's thesis on this topic.

Finally, this GoPro-based monitoring approach must deal with one more challenge: by-passers unavoidably appearing in photographs. Given that all INDIGO data become publicly available at the end of the project, it is of the utmost importance to anonymise every person or other relevant personal data (like number plates) in these photos. And again, detection robustness and speed of execution are critical. Luckily, INDIGO could already successfully test the software by Celantur. Celantur specialises in the anonymisation of still images and videos. The software blurs faces and can anonymise entire bodies, also when people are partly obscured (Fig. 69A-B) or depicted as tiny figures in highly overexposed parts of the photo (Fig. 69C). In addition, Celantur's software features annotated output with confidence values and can deliver binary photo masks. These masks can be applied at any stage of INDIGO's entire image processing workflow, ensuring that the original photos stay unaltered.

Fig. 69. The binary masks (applied in purple) generated by Celantur's anonymisation software. Entire bodies can be masked, irrespective of people's distance to the camera (close in A or very far in C). Partial occlusions (A and B), busy graffiti backgrounds (B) and overexposure (C) do not seem to impact the software's performance.

Image processing

This work package will integrate and apply all the colour correction, orthorectification, segmentation and annotation tools on the photos collected during years one and two. As mentioned above, photo anonymisation will also be applied by default. Apart from finding a good integration, this package is solely implementational and does not need any research. The majority of human power will go to the annotation step, for which the detailed graffiti knowledge of Stefan Wogrin will be of the utmost importance.

Thesaurus

Any graffiti analysis depends on how graffiti are defined and classified. For example: some scholars and graffitists voice that legally permitted graffiti do not deserve the label 'graffiti'. Even though such terminological distinctions do not guide INDIGO's recording, the project must strive for terminological clarity to populate the database with unambiguous metadata. The creation of a graffiti thesaurus must accomplish this. Being a finite set of terms (i.e., a controlled vocabulary) with hierarchical relations, this thesaurus will make INDIGO's classification explicit and hopes to serve as a reference for the broader academic graffiti community. Since the thesaurus is considered one of the essential project deliverables, it has received substantial attention. However, its construction has proved challenging, not at least because of the difficulty related to defining graffiti itself. As a concept, graffiti is used in archaeological circles to describe ancient Roman inscriptions but is equally well-used by sociologists and art historians to talk about colourful contemporary sprayings. Being an archaeological and heritage science project, INDIGO wants to consider all major and minor aspects of the term in its thesaurus. Based on this general definition, related concepts like street art and mark-making get defined, as are the countless graffiti subcategories.

Fig. 70. Some of the different structures developed in [MIRO](#) to structure the graffiti thesaurus.

Besides some fundamental problems in defining overarching terms, it has also proven hard to find a proper way to structure all terms hierarchically. Over the past twelve months, many designs have been proposed (see Figure 70 for some examples). Discussing those designs was not always straightforward since experts on thesauri are not, per se, experts on graffiti and vice versa. To aid us in this process, INDIGO has contacted the Getty Research Institute (the author of the authoritative Getty Art and Architecture Thesaurus) and influential scholars like Ann Graf. There is currently a consensus to model the entire INDIGO thesaurus structure after the AAT. How this structure can be ported to the semantic web is something INDIGO discusses with the people at the ACDH-CH.

A positive side effect of creating this thesaurus is that diverse sources about graffiti have been consulted, effectively leading to a continuously increasing reference database. This database – built in the open-source software Zenodo – will also be made available at the end of the project and likely constitute the most extensive reference database on contemporary and ancient graffiti.

Spatial database

This work package aims to create a spatial database to manage and query all (meta)data. The need for robust database integration with the online platform, support for spatio-temporal queries, and adherence to the CIDOC CRM ontology standard make this task considerably challenging. At the same time, data entry should be customisable and painless. INDIGO has chosen the CIDOC CRM-based OpenAtlas database as its solution. Because INDIGO deals with spatially 3D data and many graffiti only live for a few days, two specific but profound OpenAtlas changes were needed: 1) the support for 3D geometries and 2) a temporal resolution smaller than one year. In 2022, these features were (entirely or partially) implemented; the INDIGO staff also had the opportunity to play around in OpenAtlas to see how it operates. However, to start ingesting data, a few more requirements need to be fulfilled:

- Creating a first version of the thesaurus, implemented into a semantic framework and imported into OpenAtlas.
- Generating a sample data set with 3D geometries and metadata-rich images, enabling the OpenAtlas team to check the extra functionality needed to deal with them. This is only possible when it is clear how – and at what stage – various metadata will be embedded into the photos.

INDIGO's data processing complexity and WP interrelationships become apparent when observing Figure 71. For instance, the flowchart reveals how the thesaurus is essential for steps 2 (i.e., metadata annotation) and 4 (i.e., OpenAtlas data ingestion). At the same time, the specific implementation of step 2 is researched as well.

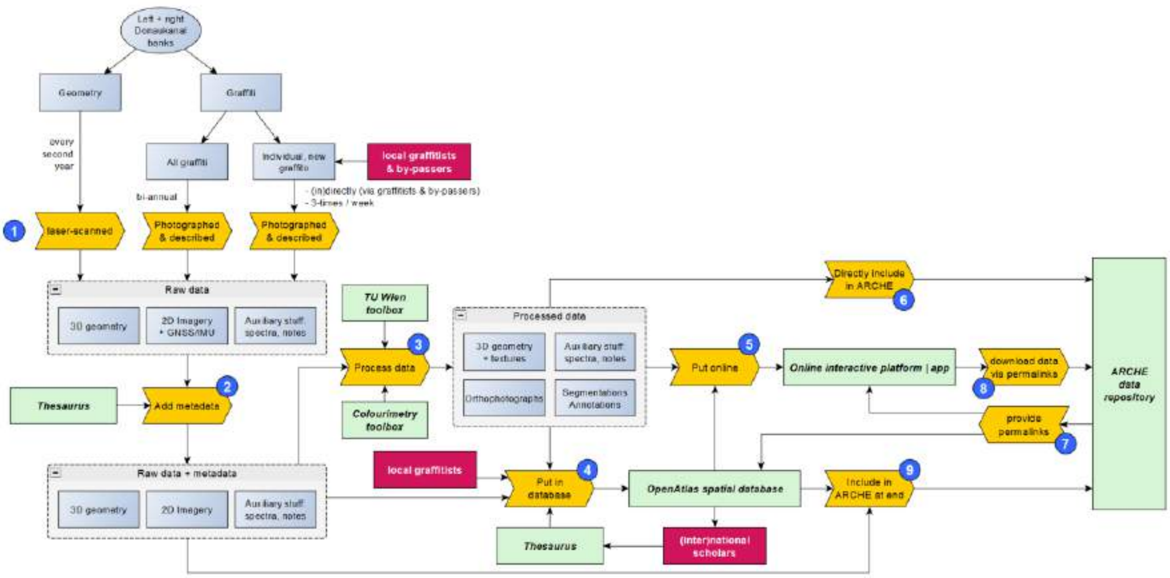


Fig. 71. INDIGO's envisioned data pipeline.

Finally, OpenAtlas might still have to add functionality to store and query temporal relationships before data ingestion can start. Spatio-temporal queries are a big deal for INDIGO, but temporality is typically given very little attention in archaeology. This also explains the lack of tools to deal with the temporal aspect of cultural heritage, despite being one of its core characteristics. Given the detailed temporal data collected in the project and knowing that spatio-temporal reasoning is the topic of Jona Schlegel's PhD, INDIGO hopes to improve upon the state-of-the-art in this aspect through the dialogue between Jona and the OpenAtlas team. Without further delays, data ingestion into OpenAtlas should start around March 2023.

Data ingestion

Data are not only ingested in OpenAtlas but also in ARCHE, the certified repository of the ACDH-CH. At the ACDH-CH, discussions have taken place on how data from OpenAtlas should flow to ARCHE (to minimise manual work) or vice versa. Data ingestion in OpenAtlas and ARCHE is expected to start in Q1 2023.

From the beginning of the project, INDIGO's graffiti overview photographs have also been integrated into the Spraycity archive. As agreed, project INDIGO gets credited (see an example here). In this way, INDIGO also supports the local and twenty-year-old graffiti database curated by Spraycity (a vital INDIGO partner).

Online platform

The open-access online platform is where all work packages culminate. The textured 3D views will allow visitors to look at present-day graffiti in their geographically correct urban setting or scroll through time and visually experience the works' time span. A section to browse through detailed graffiti orthophotographs plus functions to download and extensively query (meta)data should also be present.

Various technologies have been explored in the first project year, and the team has settled on the Cesium platform. With the fixed technological framework, the platform's wireframing phase started in September 2022. To not end up empty-handed, INDIGO will consider that the 3D platform's integration with OpenAtlas and ARCHE could still take longer than anticipated (despite the realistic plan sketched above). That is why the platform's first version will be centred around the 2D orthophotos (generated in AUTOGRAF), with all necessary database querying functionality for this 2D environment. Visualising data on a map is also more manageable than creating a smooth 3D experience. However, with the input of VRVis, specific domain knowledge gets injected into INDIGO, so achieving an interactive 3D platform still looks realistic from a technological point of view.

Data storage

Another tool that plays an essential role in project INDIGO is sync.com. Sync.com ensures that all relevant primary data get safely and quickly stored on INDIGO's central workstation (Fig. 72). INDIGO is a "big data" project. One of the three dedicated photographers collects at least once per week >100 GB of photographs. This photographer is often Stefan Wogrin from SprayCity, who does not share an office with the other two photographers. Via a two-user account with unlimited storage, data collected by Stefan are uploaded from his home computer to Sync.com's cloud service and automatically synchronised with INDIGO's central workstation. As such, a weekly physical transfer of a hard drive is avoided, thus saving precious time. Moreover, Sync.com also stores a copy of all primary and supplementary INDIGO data in the cloud. Because the service provides end-to-end zero-knowledge encryption, not even the people at Sync.com can open INDIGO data without passing a two-level verification. That is why the service was independently reviewed as the most secure Cloud Storage solution to date. Finally, the project leader's PC also stores a copy of all data.

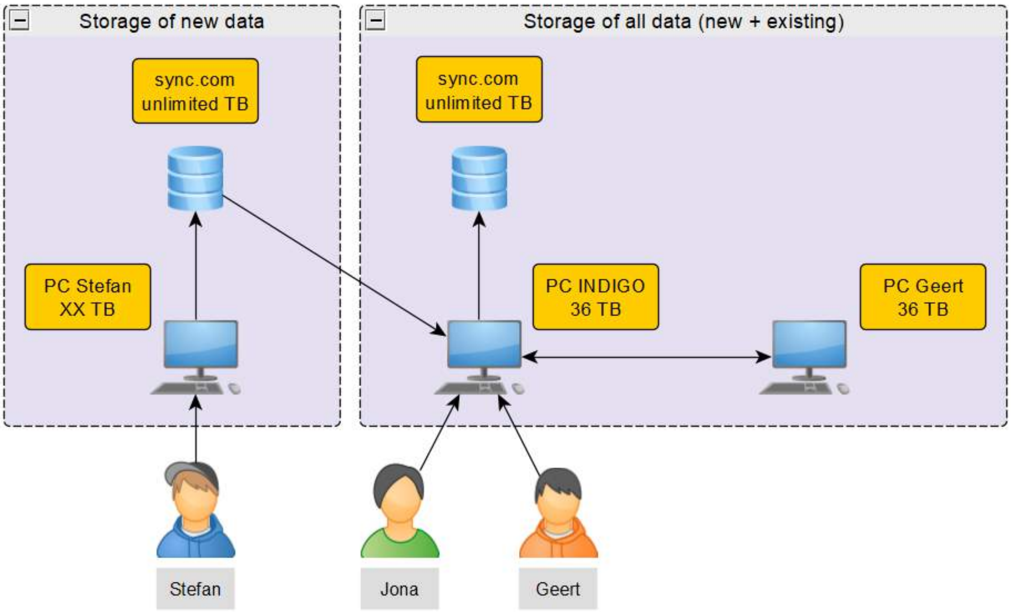


Fig. 72. Management of INDIGO's primary research data (i.e., photographs and spectrometer files).

Dissemination & Awareness

Scientific dissemination

INDIGO is an open-data and open-access project operating according to the FAIR principles. Whereas project data will become available at the project's end via the ARCHE data repository, all scientific output (papers (2), software (2) and most presentations (7)) can be found at different locations: INDIGO's Zenodo community, a dedicated ResearchGate project page, the INDIGO project website.

INDIGO has published three peer-reviewed papers by the end of 2022:

- Nocerino, E., Menna, F., Verhoeven, G.J., 2022. *Good vibrations? How image stabilisation influences photogrammetry*. Int. Arch. Photogramm. Remote Sens. Spatial Inf. Sci. XLVI-2/W1-2022, 395–400. DOI: 10.5194/isprs-archives-XLVI-2-W1-2022-395-2022
- Verhoeven, G.J., Wild, B., Schlegel, J., Wieser, M., Pfeifer, N., Wogrin, S., Eysn, L., Carloni, M., Koschiček-Krombholz, B., Molada-Tebar, A., Otepka-Schremmer, J., Ressl, C., Trognitz, M., Watzinger, A., 2022. *Project INDIGO – document, disseminate & analyse a graffiti-scape*. Int. Arch. Photogramm. Remote Sens. Spatial Inf. Sci. XLVI-2/W1-2022, 513–520. DOI: 10.5194/isprs-archives-XLVI-2-W1-2022-513-2022.
    - This article won the best paper award at the 3D-ARCH 2022 conference.
- Wild, B., Verhoeven, G.J., Wieser, M., Ressl, C., Schlegel, J., Wogrin, S., Otepka-Schremmer, J., & Pfeifer, N., 2022. *AUTOGRAF—Automated Orthorectification of GRAFfiti Photos*. Heritage 5(4), 2987–3009. DOI: 10.3390/heritage5040155.

For presentations in 2022 see chapter 9.5 (Scientific publications and presentations 2022). As of the end of 2022, one edited volume and seven papers are submitted to be forthcoming in 2023.

Public dissemination

From the start of the project, INDIGO had a project website online: https://projectindigo.eu. This website contains all relevant project info (which gets regularly updated and expanded) and features a blog section. Every two weeks, INDIGO publishes a newsletter featuring a short mention of all upcoming meetings, a photograph of a graffito recently created along the Donaukanal (clicking on this image brings up a map with its location) and a short description and link to the protocol of past meetings. These meeting protocols are freely accessible to anybody on the INDIGO website.

Since 2022, project INDIGO has an active Instagram account, because it is one of the main platforms where the necessary engagement with graffiti creators occurs. In one year, almost 400 people active in the graffiti scene started to follow INDIGO's Instagram. The Twitter account of project INDIGO is mainly used for advertising all the talks of the goINDIGO 2022 symposium.

The Austrian newspaper Die Presse devoted an article to project INDIGO (16.07.2022, https://projectindigo.eu/diepresse). Additionally, the project was presented at the Lange Nacht der Forschung 2022 and the European Researchers' Night 2022 in Vienna, Austria. On www.theworldinpointclouds.com, INDIGO is featured in a blog post on point cloud generation and has been mentioned on two podcasts (ILOVEGRAFFITI.DE Podcast 69: https://www.youtube.com/watch?v=wf-L2Ysuqn0, Artcade podcast S08 E01: https://artcadepodcast.podbean.com/e/s08-e01-ndzw.

The Levin Statzer Foundation started to organise boat tours in September and October 2022 along the graffiti-scape of the Donaukanal. During these tours, project INDIGO and its goals are mentioned.

Awareness

INDIGO deals with multi-coloured content, often created by people referring to themselves as artists. That is why the graphical work always received the necessary attention. Social media like Instagram and, to a lesser extent, Twitter are also important for INDIGO, because they establish the necessary local engagement with the local graffiti community. Besides the usual public dissemination and academic dissemination (as outlined above), INDIGO also spreads project awareness via the graffiti tours and workshops organised by Spraycity which establishes the necessary link between the academic and non-academic graffiti communities. The three project photographers that frequently visit the Donaukanal have business cards with personalised QR codes that link to the website and the online form to report new graffiti (Fig. 73).

Fig. 73. The front (on the left) and back (on the right) of Jona Schlegel's INDIGO business card. The QR codes are personalised and link to the general website and the online reporting form.

Conferences and workshops

In 2022, INDIGO staff attended various national and international gatherings, i.e. SynerGIS After Business Workshop, topic "SURE" (online event), 3D-ARCH'2022 - 3D Virtual Reconstruction and Visualization of Complex Architectures – 9th International Workshop (Mantova, Italy), Pointcloud Workshop (Geospatial Research Innovation Development lab at the University of New South Wales, online event), goINDIGO 2022: document | archive | disseminate graffiti-scapes (Vienna, Austria), ARIADNEplus workshop: Semantic mapping of excavation data (online event), ARIADNEplus Summer School: Mapping Existing Datasets to CIDOC CRM **(**Prato, Italy), Third Heritage Science Austria Meeting (Vienna, Austria).

Because INDIGO has a technical- and more humanistic-oriented aspect, both facets were planned to be covered by two symposia. **goINDIGO2022** had been planned to take place six months into the project and tackle all the technical, logistic, legal, and ethical aspects of documenting, archiving, and disseminating graffiti. Although the uncertainty created by the COVID-19 pandemic slightly delayed the goINDIGO 2022 symposium and made a hybrid event inevitable, INDIGO managed a small but successful gathering. From the 11th to the 13th of May 2022, a mixed group of sixty participants (graffiti creators, heritage professionals and graffiti academics) from twelve countries met in Vienna or online to learn from each other and build proverbial bridges. Throughout two and a half days, two keynote lectures and eighteen presentations touched upon many facets of documenting, archiving and disseminating graffiti records (see also the book of abstracts). The proceedings of the symposium are expected by the end of March 2023.

A second symposium – goINDIGO 2023 – is planned for the end of the project. This gathering should focus on graffiti's socio-political and cultural impact. goINDIGO 2023 will also mark the launch of INDIGO's online platform and showcase how its stored graffiti (meta)data enables societal and cultural insights.

Appendix "Media Coverage 2022"

LBI ArchPro misc.

online

- https://www.krone.at/2603862
- https://www.diepresse.com/6165934/graffiti-am-donaukanal-buntes-erbe-zum-lachen-aergern-und-gruebeln
- https://www.noen.at/mistelbach/herrnbaumgarten-viertelfestival-luftschloss-endlich-gefunden-herrnbaumgarten-viertelfestival-nonseum-fritz-gall-karl-wilfing-print-327422766
- https://m.bvz.at/bvz-aktionen/bvz-praesentiert/edition-roemer-blut-und-sand-die-gladiatorenschule-in-carnuntum-wiederentdeckt-336671505
- https://www.noen.at/noen-aktionen/noen-praesentiert/edition-roemer-carnuntum-weltstadt-am-donaulimes-edition-roemer-336671012
- https://www.noen.at/noen-aktionen/noen-praesentiert/edition-roemer-blut-und-sand-die-gladiatorenschule-in-carnuntum-wiederentdeckt-336671505

print

- Buntes Erbe zum Lachen, Ärgern und Grübeln (Der Standard, W3, 16.7.2022)
- „Darf ich mich vorstellen, ich heiße Peggi!" (Kronen Zeitung/Steiermark Morgen, S.26, 16.01.2022)
- Fliegen auf Sicht (trend, Nr. 13/2022, 09.09.2022, S. 42-45, Ressort: Österreich)
- Blut und Sand – Die Gladiatorenschule in Carnuntum wiederentdeckt; von Wolfgang Neubauer (NÖN edition Geschichte, Die Römer, Oktober 2022, S. 72-77)
- Neue Methoden der Archäologie; von Wolfgang Neubauer (NÖN edition Geschichte, Die Römer, Oktober 2022, S. 71)
- Fünf Tage Sphinx und Pyramide (Kurier History Nr. 01/2022, 100 Jahre Tutanchamun, 06.10. 2022, S. 93)

Schlacht am Marchfeld

online

- https://science.orf.at/stories/3210776/
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