Comparison of GPR results with UAV photogrammetry at a Roman *villa rustica* in *Noricum* (southern Bavaria)

Roland Linck[1,2*], Andreas Stele[1], Tatjana Gericke[1]

1 Bavarian State Department for Monuments and Sites (BLfD), Munich, Germany
2 Ludwig-Maximilians-University, Department of Earth and Environmental Sciences, Munich, Germany
* Corresponding author: E-mail: roland.linck@blfd.bayern.de

Abstract
Ground penetrating radar was used for mapping the layout of a Roman villa rustica. Adjacent rescue excavation results were mapped by UAV photogrammetry. The combination with a photogrammetric model enables a ground truthing of GPR results.

Keywords
ground penetrating radar; ground truthing; Noricum; Roman villa rustica; UAV photogrammetry

Introduction

Compared with other geophysical prospection methods, ground penetrating radar (GPR) has the huge advantage that it generates results in 3D due to the measurement of the signal travel time. Based on the travel time, the depth of the archaeological remains can be estimated. However, ground-truthing of the estimated depth rarely occurs by other methods like excavation maps. Some examples were published recently, e.g. by Baret (2021), Gamon et al. (2021), Paez-Rezende and Hulin (2021), Linck et al. (2022). Within this study a comparison of GPR depth slices with the digital imaging of excavation results will be presented.

The test site was a Roman villa rustica near Prien am Chiemsee in southern Bavaria. Despite several buildings of the villa having already been excavated during the first half of the 20th century, a small area was opened in 2021 during construction work surprisingly revealing a part of another Roman villa building. To evaluate the layout of the whole monument, the adjacent area was mapped by GPR in 2022. As the detected, but not yet archaeologically documented, remains were still uncovered during the survey, we used this opportunity to map the walls in detail and with high precision by an Unmanned Aerial Vehicle (UAV) flight. Hence, results from the geophysical survey can be compared with the directly adjacent excavation trench to gather an information on the accuracy of the estimated depth in the GPR data because some of the walls in the trench continue towards the survey area.

Survey instruments

The GPR survey was executed at an 80 x 34 m area directly adjacent to the archaeological excavation trench. The GSSI SIR-4000 was used with a 400 MHz antenna and a sample spacing of 6 x 50 cm was chosen to provide an ideal imaging of the buried archaeological remains within reasonable time. A Time-Domain-Reflectometry (TDR) measurement was also conducted once per hour to quantify relevant soil parameters. The TDR survey showed a quite high soil moisture level of averaged 51 vol% due to the local geology consisting of pseudogley-brownearth on top of gravel moraine. This results in a huge dielectric value ε_r of 20-35. The value fits to the estimated one at reflection hyperbolas in the GPR data. However, the measured soil conductivity with 1.1 dS/m was quite low and the area was still suitable for

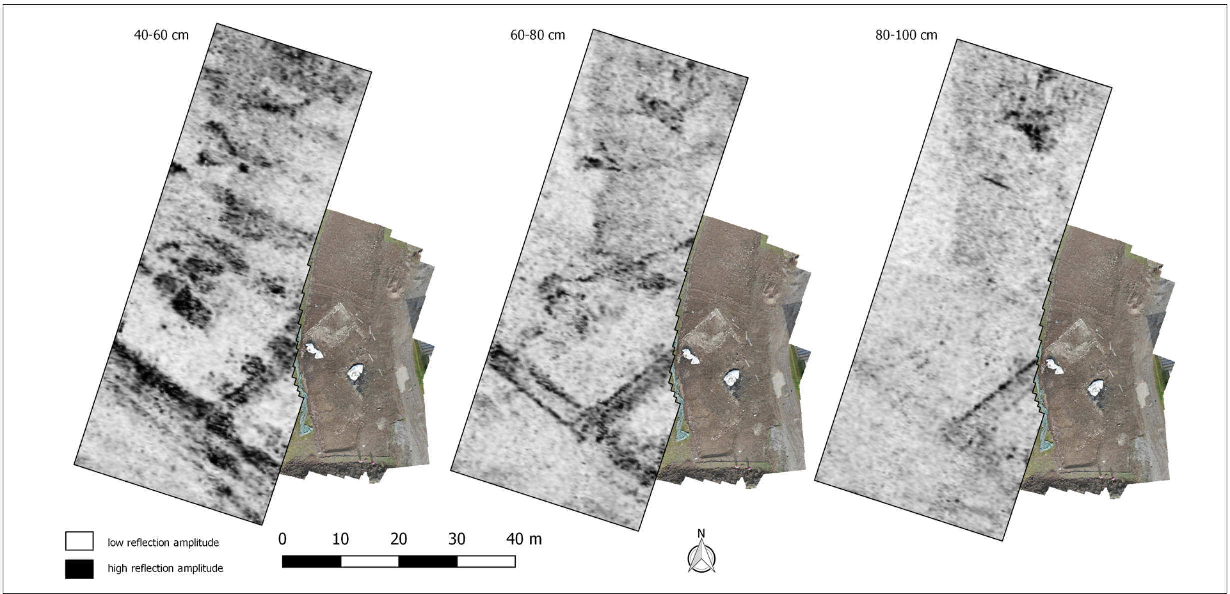

Fig. 1: Georeferenced overlay of selected GPR slices in the relevant depth range with the photogrammetric orthophoto of the excavated part of the building. GSSI SIR-4000 with 400 MHz antenna; sample interval: 6 x 50 cm (Archive No. Pri22rad). DJI Mavic 2 Enterprise; resolution: 3 mm, acquisition date: 18.03.2022 (Archive No. Pri22uav).

Fig. 2: Perspective view on the photogrammetric model of the excavated Roman remains showing the actual depth location of the walls. DJI Mavic 2 Enterprise; acquisition date: 18.03.2022 (Archive No. Pri22uav).

a successful GPR survey, as the archaeological remains were known to be quite shallow.

The photogrammetric survey of the excavated part of the Roman building was made with a DJI Mavic 2 Enterprise drone operating at 17 m flight altitude and covering the 980 m² large area with 71 densely overlapping images. This resulted in an orthophoto (DOP) with a resolution of 3 mm providing a detailed image of the visible remains. To ensure a 1-3 cm accuracy of the drone data, the relevant area was surrounded by four reference points surveyed with RTK-GNSS.

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Fig. 3: GIS-based interpretation map of the results of GPR and excavation showing the layout of the Roman buildings in this part of the villa rustica of Prien am Chiemsee.

Results and discussion

The radargram shows the Roman remains at a depth of 30-80 cm below the modern surface (Fig. 1) and therefore only 50 cm of the walls have been preserved. This is confirmed by the excavation results that reveal the first Roman remains in 40 cm below the top soil (Fig. 2). As visible in the trench, the walls seem to exist only of the last stone packages of the fundament (ca. 20-30 cm thickness), consisting of rubble and cobble stones. The bottom surface of the structures thus is overestimated in GPR. The reason is that inside the walls the physical parameters differ from the surrounding soil. Therefore, the parameters used for the depth estimation are not valid for the walls themselves. This is a serious concern for archaeologists and heritage management.

Combining the GPR depth slices and the photogrammetry results, a northeast-southwest oriented Roman building of 28.5 x 17 m size can be reconstructed (Fig. 1 and 3). Especially the depth slices of 60-80 cm and 80-100 cm below the modern surface show that the building consisted of a double wall structure, i.e. a ca. 70 cm thick outer wall and another parallel one in 2.5 m distance. In between the GPR data shows a strong reflective infill with smaller stones or a preserved floor. The same layout can be seen in the excavation results. Possibly these features can be interpreted as single rooms arranged in a row along the outer side of the building, whereas the separating walls have not been preserved. Only the northernmost of these rooms is clearly visible in the UAV DOP. The southern corner of the building is only vaguely detectable in the radargrams but can be reconstructed by the junction of the southwestern wall in the GPR data and the southeastern one visible in the DOP. This demonstrates how well both methods can be combined to assist with mapping the complete Roman building. Along the northwestern part of the monument, the 40-60 cm depth slice reveals a 2.5 x 3.5 m rectangular anomaly with a quite strong reflection amplitude. This feature can probably be interpreted as part of a collapsed wall that is buried in-situ.

Directly south and in the northwest of the stone building, the radargrams show further rubble concentrations. Two of the northwestern ones possibly also belong to stone buildings due to their rectangular shape. These subsidiary buildings would have a size of 7 x 4 m and 5 x 8 m. The other reflective anomalies are not definitely of archaeological origin, but could also be of geological origin, e.g. parts of the moraine.

Directly adjacent of the described southernmost big stone building, a northeast-southwest aligned, 3 m wide linear anomaly with higher reflection amplitude is visible. This structure can be interpreted as a road. As its orientation does not fit to the detected Roman building and the structure lies a bit shallower, the road possibly dates to a later period; probably the Middle Ages or even Modern Period, as it is not marked on 19th century maps.

Conclusion

The presented integrated survey shows, how geophysical methods and drone photogrammetry fit together in creating a comprehensive map of an archaeological site. As the feature depth in the excavation and the GPR depth slices is similar, it can be concluded that the calculated values for GPR data fits quite well here, as both provide a value of 30-40 cm below the modern surface. However, a more precise analysis would require comparison between GPR survey data and a subsequent excavation of the same area, opposed to the adjacent areas shown here.

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