GROUND PENETRATING RADAR (GPR) APPLICATIONS

Transylvania (Romania) 2020

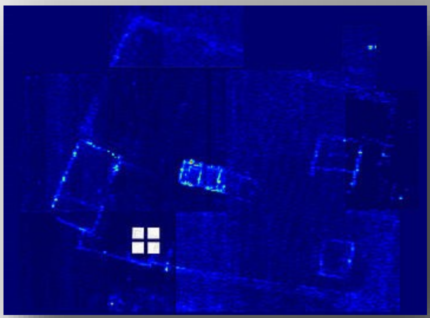
APPLIED FIELD GEOPHYSICS WORKSHOP:

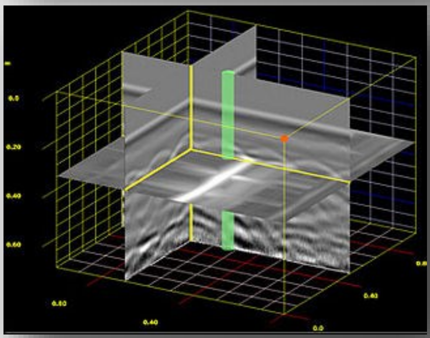
Session 1: June 14 - June 20
Session 2: June 21 - June 27
Session 3: July 12 - July 18
Session 4: July 19 - July 25

GEOPHYSICS EXPLORATION AND ARCHAEOLOGY EXCAVATION:

Session 1: June 7 - July 4, 2020
Session 2: July 5 - August 1, 2020

This workshop aims at providing **intensive training** in **applied field geophysical methods,** in an extraordinary environment in Southern Transylvania (Romania). Geophysical methods are an extremely versatile set of techniques used extensively in both research and practical applications from archaeology, to urbanism, forensics, geology, engineering. Field experience with these techniques is an exceptionally useful and lucrative skill to acquire, but training in these methods is limited to expensive manufacturer professional development and/or academic courses. Our workshop offers a full set of technical, theoretical, and practical skills for **Ground Penetrating Radar (GPR)** surveying. It provides thorough training for field work, processing, and interpretation of intensively modified human landscapes, in an accessible and professional way. Hands-on experience is an essential complement to previous or planned geophysics training for work in earth sciences, geology, geography, urban planning, architecture, surveying, civil engineering, environmental engineering, environmental studies, landscaping, forensics, anthropology, archaeology, cultural resource management (CRM), Classics, and/or history. Working in teams of two or three, participants will maximize both quantity and quality of acquired field and analytical geophysical exploration skills, working on the two systems most used in near-surface investigations (i.e. down to 4m/13ft): 250MHz and 500MHz, in rough terrain and cart configurations.





PROGRAM FEES:

- 5-day GPR session: $1095
- 4-week GPR and excavation session: $2295

INCLUDED: lectures and labs; survey gear; site clearance; full room and board for the duration of the GPR Workshop; local transportation to survey locations

FOR MORE INFORMATION:

https://www.archaeotek-archaeology.org/applied-field-geophysics-gpr

OR CONTACT US:

archaeology@archaeotek.org

APPLIED FIELD GEOPHYSICS RESEARCH workshop
- GROUND PENETRATING RADAR APPLICATIONS -

Summer 2020
Southern Transylvania, Hunedoara County, Romania

ArchaeoTek Canada

Ground Penetrating Radar Workshop Dates:

Session 1: June 14 – June 20
Session 2: June 21 – June 27
Session 3: July 12 – July 18
Session 4: July 19 – July 25

Geophysical Exploration (GPR) and Roman Archaeological Excavation:

Session 1: June 7 – July 4, 2020
Session 2: July 5 – August 1, 2020

Scientific Director: Dr. Andre Gonciar (archaeology@archaeotek.org)

Web Site:
https://www.archaeotek-archaeology.org/applied-field-geophysics-gpr

Application Form:
https://www.archaeotek-archaeology.org/application-excavation-and-gpr

Application Form:

- GPR Workshop: $1095 per 5-day session
- GPR Exploration and Archaeological Excavation: $2295 per 4-week session

I. Introduction:

This workshop aims at providing intensive training in applied field geophysical methods in an extraordinary environment in Southern Transylvania. Geophysical methods are an extremely versatile set of techniques used extensively in both research and practical applications from archaeology, to urbanism, forensics, geology, and engineering. Field experience with these techniques is an exceptionally useful and lucrative skill to acquire, but training in these methods is limited to expensive manufacturer professional development and/or academic courses. These educational opportunities otherwise available tend to sacrifice either the theoretical and technical foundations, or the practical use and interpretation of the methods. In contrast, this workshop provides a full set of technical, theoretical, and practical skills for Ground Penetrating Radar (GPR) surveying. As such, it offers thorough training for field work, processing, and interpretation of intensively modified human landscapes in an accessible and professional way. Hands-on experience is an essential complement to previous or planned geophysics training for work in earth sciences, geology, geography, urban planning, architecture, surveying, civil engineering, environmental engineering, environmental studies, landscaping, forensics, anthropology, archaeology, cultural resource management (CRM), Classics, and/or history.

This workshop will address the basic principles of electromagnetic wave propagation and electromagnetic properties as they apply to GPR and geophysical exploration. We will focus on the practical applications of GPR in a variety of disciplines in order to achieve the most useful results for a specific environment with distinct stratigraphic and geological properties. The workshop will be progressively staged so that participants gain experience and skills required to formulate appropriate research questions and carry out real life data collection and analysis to answer those questions. During the first two days, participants will receive several lectures on GPR theory and method, learn to properly collect data and use the field equipment as well as the analytical software. The last three days will be devoted exclusively to data collection and analysis, designed to acquire the maximum applied field geophysical experience. The culmination of the workshop will be a presentation of the results to develop participant's skills to communicate geophysical results. Working in teams of two or three, participants will maximize both quantity and quality of acquired field and analytical geophysical exploration skills. Our participants will get intensive comparative training on the two most used systems in near-surface investigations, respectively 250 MHz and 500 MHz transducers in rough terrain and cart configurations.

II. Course Aims and Outcomes:

Aims

Upon completion of this workshop, participants will have the skill set and knowledge required to plan, conduct, analyze, and interpret successful GPR surveys in any terrestrial setting. This process will present a variety of anthropogenic and natural challenges, from working in diverse field conditions, to dealing with sites containing a combination of known and unknown modern and historical features. The whole experience is intended to be intensive and collaborative, with a focus on experiential learning and application of processing, collection, and interpretation methods to real sites under real life research conditions. Participants will work directly with our instructors in small groups of 2-3 per system to gain fluency and proficiency with the equipment, software, and logistics of a GPR project. At the end of each session, the data will be presented as a full professional report, both in writing and as an oral podium presentation.

Applications and Case Studies

The workshop is conducted in the heart of Transylvania, in the Mureş river valley (Hunedoara County, Romania). This region combines intensive historical human habitation and landscape transformation with relatively static modern occupation, offering complex but highly accessible study sites. This offers a unique setting in which common environmental challenges to a GPR survey, such as interference from cell phone towers, communication and power lines, road traffic, and modern constructions occur at recognizable and manageable levels. As a result, this location is ideal for both GPR exploration and intensive skill acquisition.

Our target case study sites, the Roman castrum and municipium of Micia and the medieval castle of Uroi, show distinct urban elements (without the extraneous clutter of modern urban environments) of various size, shape, orientation, depth and composition, ideal for GPR training at both formative and advanced levels.

Roman Micia is one of the largest and most intricate archaeological urban sites in Transylvania, featuring three centuries of Roman occupation. Beginning as complex fortified military camps, it later expanded into a large village and then a full city, complete with amphitheater, baths, temples, manufacturing, shops, plazas, large and small habitation structures, and two cemeteries with funerary monuments. The Roman site was then taken over by migratory people with variable architectural skill who modified the site according to their needs and perception for over four centuries. It was then forgotten for close to a millennium and a half until, during communist times, a thermal power plant and a couple of roads were built on the site, destroying about 20% of it, and introducing a modern twist to our GPR research area in the form of unmapped buried utilities and buried support/temporary structures.

The medieval castle of Uroi, now mostly in ruins, lies on the edge of the modern village of Uroi. It was a small military castle, heavily fortified with large solid walls, running deep. As a result, the Uroi environment presents a strong archaeological contrast with the Roman features from Micia, allowing for the unique opportunity for comparative analysis both in terms of feature recognition, and system applicability and optimization.

These sites thus provide unparalleled access to a diverse set of features and conditions. We address urban and proto-urban settlement construction, complex anthropogenic stratigraphic relationships, variation in soil structure and conditions, a wide range of materials and their use/reuse, unmapped ancient and modern utilities, potential graves, modern and ancient civil works projects (including the remains of roads, aqueducts, and wells), changes in hydrogeological environment caused by modern human intervention (construction and operation of thermal power plant), and any additional undiscovered features.

Specific Learning Outcomes

We aim to provide contextualized information about the technical and practical aspects of GPR surveying, fully applicable to GPR work in all disciplines. After a comprehensive introduction to the equipment and survey procedures, we will conduct intensive surveys to map both the modern and historical features at Micia and Uroi using both GPR systems (250MHz and 500MHz) in both field configurations (rough terrain and cart). The results of this survey will be formally presented in a professional setting at the end of each session. In addition to providing hands-on experience and associated skills required by employers (field assesment, technical and geophysical surveying, oral and written presentation of the data, etc.), we will have supplemental discussions and readings on more advanced GPR topics and specific applications (for example, qualitative and quantitative identification of subsurface features). At its core, the workshop is designed to provide an engaging environment for the acquisition of the fully transferrable skills and knowledge at the core of all GPR applications and projects.

Students who want to expand their skill set to field archaeology can register to our Geophysical Exploration and Archaeological Excavation. It is a 4 week program resulting from the combination of our Applied Field Geophysics Workshop and Roman Villa and Settlement Excavation and Survey (and save $195 on the combined cost of the two programs).

This course will equip participants with the skills and experience needed to:

Conduct successful GPR projects from conceptualization through completion

- Select the appropriate geophysical method for particular objectives and conditions
- Understanding of the advantages and disadvantages of each system and configuration, resulting in the capacity to choose the optimal system for the task at hand
- Define and prioritize feasible data collection objectives according to urgency, required results, data quality and quantity, and accessibility
- Identify survey costs (data storage and processing, collection time, labor, seasonal factors, and equipment) related to specific goals and objectives
- Execute efficient and successful field surveys
- Meaningfully process and interpret data for particular project objectives
- Create clear visuals that convey results
- Communicate results clearly and completely to technical and non-technical audiences

Properly understand and identify constraints of GPR surveys in actual environments

- Identify the conditions under which a GPR approach is applicable
- Use technical foundations of the GPR method to understand the different kinds of information that can be gained from GPR survey and how this information might change with field conditions
- Recognize how external constraints such as weather impact the feasibility of particular objectives and/or implementation of specific geophysical methods

Proficiency operating GPR field equipment

- Identify and understand nature and use of field equipment required for conducting surveys
- Properly assemble and disassemble the equipment, in both field configurations
- Full training and troubleshooting with Noggin 500 and Noggin 250 (Sensors and Software) GPR Units in Smart Tow/Rough Terrain and Smart Cart Configurations

Understand and execute useful GPR surveys in the field

- Optimize field coverage, grid location, and collection type according to survey goals
- Understand data quality and quantity in relation to data collection method, equipment settings, calibrated parameters, and field contexts
- Identify optimal data collection method for each context
- Evaluate locations and sites to address specific research questions
- Properly locate and prepare different types of survey sites (grid, line survey, GPS, etc.)
- Identify and collect external auxiliary non-GPR data essential for post processing and interpretation of GPR data

Perform meaningful GPR post-processing and interpretations

- Process data into scans (radargrams) and slices using the EKKO Project suite and Sliceview (Sensors and Software), transferrable to most GPR processing software suites
- Interpret a wide range of anthropogenic and natural features in GPR data, including walls, floors, roads, destruction levels, funerary features, utilities, and geological changes
- Distinguish between meaningful reflections, spurious signals, and artifacts of the data
- Apply depth slicing, velocity analysis, grid stitching, and GPS positioning data to create interpretive maps of subsurface features from multiple grids
- 3D visualization of research context and results

III. Format and Procedures:

This workshop is structured as an intensive five-day GPR training course conducted in an archaeological/historical environment with well-defined modern interferences and activity. For processing data and compiling results, it is helpful for participants to bring a Windows laptop if possible. The software can only be installed on this operating system (Windows 7 or newer, or a Windows emulator like Bootcamp for MacOS) and can only be used in the lab according to software licensing. Even if you do not have Windows, a laptop will likely be necessary to complete and review readings and work on the final presentation. Please contact one of the directors if you have computing concerns.

Participants will be guests of Romanian families in Rapolt for the duration of the workshop. Full room and board will be provided for each workshop session. Meals will consist of traditional Romanian cuisine and can be prepared to accommodate vegetarian diets. The small size of our field teams, 2-3 per GPR system, is designed to provide extensive personalized instruction and the ability to tailor the workshop to the interests of participants. Local transportation to field sites will be provided as needed.

The workshop is meant to be an intensive program, maximizing the integration of theory, method and experiential knowledge/skill. As such, each day will contain 7-9h of workshop related activities. The tentative daily schedule – for more details, see **Course Schedule** below – is as follows (*subject to change*):

- 6:30AM: Breakfast
- 7-7:30AM: Beginning of morning lectures, laboratory work and/or field surveying
- 12:30PM: Lunch
- 1:30PM: Beginning of afternoon lectures, laboratory work and/or field surveying
- 4:30PM (or later, as needed): End on work day
- 7PM: Dinner

Note that the basic introductory training program offered by Sensors and Software (SenSoft), one of the leading North American companies in GPR manufacturing and research, respectively the ONE Day GPR Short Course, costs **$400**. The GSSI introductory TWO Day Short Course, the other North American leading GPR company, costs **US$800**. Their classes usually run with 6-12 participants (or more), room and board not included.

IV. Participation Assumptions

This workshop focuses on extensive skill acquisition rather than academic progression. However, in registering for the course, it is assumed that participants will be engaged, interested, and active in the workshop. All workshop activities are mandatory. A substantial degree of personal responsibility and initiative is expected and required from all participants to complete readings, prepare for discussions, and acquire the skills offered in the workshop. All acquired skills and enjoyment of this workshop are directly proportional to the effort and attention participants invest. It is assumed that participants will fully engage in all aspects of the workshop.

Once accepted to the program, a set of articles and a list of introductory videos will be provided to participants. **It is absolutely essential that participants are fully versed in this prerequisite information prior to their arrival to the workshop**.

GPR surveying is physical labor. You must be able to repeatedly carry 30lbs a distance of 50m (160ft), on uneven ground, for about 1.5-2.5h per day. Field work will range from 1-2h (first day) to 4-5h daily (following days). Please contact the directors with any concerns.

Participants are encouraged to share their particular interests with the instructors, who will do their best to personalize the workshop and maximize the acquisition of relevant knowledge and skills.

All participants are expected to behave respectfully at all times towards the staff, other participants and local people. All participants are required to abide by the rules and regulations of the workshop as well as Romanian laws. Disrespectful and/or disruptive behavior will not be tolerated.

V. Course Schedule (*Subject to change*)

Readings will be provided to participants before their arrival in Romania. **Readings should be completed as *prerequisites* and reviewed before the day they are listed**. Several videos on data processing using the EKKO software suite will be provided for participants to view as prerequisites to the program. Additional reference materials containing specific technical details will also be provided for the interested participant and future reference. Each workshop session will conclude with a presentation and report of the session's findings in a professional-like environment.

The program includes, for each session, a minimum of:

- 14h lectures and seminars
- 6h laboratory instruction
- 15-20h field surveying
- 10-15h data processing and analysis

TOPICS (AM)	TOPICS (PM)	READINGS
DAY 1 **Lecture**: The Short Intro to GPR (1h) **Field**: Equipment assemble/disassembly (1h) **Field**: Locate and Mark (2h)	**DAY 1** **Lecture**: EM wave propagation and GPR Principles (1.5h) **Lecture**: GPR Surveying Basics, history, and reports (1.5h) **Lab**: Interpretations for locate and mark and sample scenarios (1.5h)	[prereq] SenSoft webinars on EKKO [1] Annan 2001 [2] Conyers 2016a
DAY 2 **Field**: Rapolt Gridded Survey I (3-4h) **Lecture**: Another look at GPR Interpretation (1h) **Lecture**: More advanced GPR Principles: Gain, attenuation, and more (1h)	**DAY 2** **Lecture**: GPR Principles: Thinking like a wave (1h) **Lab**: Processing GPR data for interpretation: using EKKO software (2h)	[3] Conyers 2016b [4] Takahashi 2012
DAY 3 **Field**: Micia Survey I (4-5h)	**DAY 3** **Lab**: Processing with maps, slices, and surfaces (2h) **-** Introduction to field data processing (Micia) **Lecture and discussion**: Comparing remote sensing approaches (1h) **Lecture:** Review of acquired methods and techniques (1h)	[5] Verdonck et al. 2008 [6] Damiata et al. 2017 [7] Pincus et al. 2013
DAY 4 **Field**: Micia Survey II or Uroi Survey I (4-5h)	**DAY 4** **Lab**: Micia or Uroi Processing (as needed) **Discussion**: Attribute Analysis, Velocity, and Gain (1h)	[8] Zhao et al 2013 [9] SenSoft concrete [10] dos Santos 2014 [11]Olhoeft 2000 SenSoft webinar: Qualitative to Quantitative [4]Takahashi 2012
DAY 5 **Field**: Uroi Survey I or II (4-5h)	**DAY 5** **Lab**: Uroi Processing (as needed) **Discussion**: Modeling and Inversion, Quantitative Analyses (1h) **Summary and Discussion** (1h) **Presentation of Results** (1h)	

VI. Prerequisite SenSoft Webinars - Proceed in the order below, after reading [1] and [2], and using glossary from [2] for reference (see Required Readings for [1] and [2])

Getting the most from your GPR Utility Data: https://www.youtube.com/watch?v=Mae_uFvOTFo
EKKO Project Utilities: https://www.youtube.com/watch?v=Znxslp5tqpY
GPR Software: EKKO_Project v5: https://www.youtube.com/watch?v=UXc-47f2GyA
SliceView GPR: https://www.youtube.com/watch?v=sv3sQHp6NeQ
Qualitative to Quantitative Analysis: https://www.youtube.com/watch?v=5IPpKGEK4R8

VII. Required Readings (Provided)

[1] A. P. Annan, "GPR – Trends, history, and future developments," in *Proceedings of the EAGE 2001 Conference*, 2001, no. 905.
[2] L. B. Conyers, Ground Penetrating Radar for Geoarchaeology. Ch. 1,2 Wiley, 2016.
[3] L. B. Conyers, "Ground-penetrating radar mapping using multiple processing and interpretation methods," *Remote Sens*., vol. 8, 2016.
[4] K. Takahashi, J. Igel, H. Preetz, and S. Kuroda, "Basics and Application of Ground- Penetrating Radar as a Tool for Monitoring Irrigation Process," in *Problems, Perspectives, and Challenges of Agricultural Water Management*, M. Kumar, Ed. InTech, 2012.
[5] L. Verdonck, D. Simpson, W. Cornelis, A. Plyson, and J. Bourgeois, "Analysing the velocity of ground-penetrating radar waves: A case study from Koekelare (Belgium)," in *1st Workshop on Remote Sensing for Archaeology & Cultural Heritage Management, Rome*, 2008, no.399
[6] B. N. Damiata, J. M. Steinberg, D. J. Bolender, G. Zoega, and J. W. Schoenfelder, "Subsurface imaging a Viking-Agee churchyard using GPR with TDR: Direct comparison to the archaeological record from an excavated site in northern Iceland," *Journal of Archaeological Science: Reports*, vol. 12, pp.244-256, 2017.
[7] J.A. Pincus, T.S. de Smet, Y. Tepper, and M.J. Adams, "Ground penetrating radar and electromagnetic archaeogeophysical investigations at the Roman legionary camp at Legio, Israel," *Archaeological Prospection*, vol.20 pp. 175-188, 2013.
[8] W. Zhao, E. Forte, M. Pipan, and G. Tian, "Ground Penetrating Radar (GPR) attribute analysis for archaeological prospection," *J. Appl. Geophys.*, vol. 97, pp. 107–117, 2013.
[9] Sensors & Software, "Concrete Scanning with GPR Guidebook." 2015
[10] V. R. N. dos Santos, W. Al-Nuaimy, J. L. Porsani, N. S. T. Hirata, and H. S. Alzubi, "Spectral analysis of ground penetrating radar signals in concrete, metallic and plastic targets," *J. Appl. Geophys.*, vol. 100, no. January, pp. 32–43, 2014.
[11] G. R. Olhoeft, "Maximizing the information return from ground penetrating radar," *J. Appl. Geophys.*, vol. 43, pp. 175–187, 2000.

VIII. Optional Readings and Helpful References

General References

A.P. Annan, Ground Penetrating Radar Principles, Procedures, and Applications. Mississauga: Sensors and Software Inc., 2003.

T. Bergmann, J. O. A. Robertsson, and K. Holliger, "Finite-difference modeling of electromagnetic wave propagation in dispersive and attenuating media," Geophysics, vol. 63, no. 3, pp. 856–867, 1998.

L. B. Conyers and D. Goodman, Ground Penetrating Radar: An Introduction for Archaeologists. Walnut Creek: AltaMira, 1997.

L. B. Conyers, Ground-Penetrating Radar for Archaeology, 2nd ed. Oxford: AltaMira, 2004.

L. B. Conyers, Ground Penetrating Radar for Geoarchaeology. Wiley, 2016.

J. J. Daniels, "Ground Penetrating Radar Fundamentals," 2000

D. Goodman and S. Piro, GPR Remote Sensing in Archaeology. Springer Berlin Heidelberg, 2013.

L. Peters Jr, J. J. Daniels, and J. D. Young, "Ground Penetrating Radar as a Subsurface Environmental Sensing Tool," Proc. Ieee., vol. 82, no. 12, pp. 1802–1822, 1994.

Forensic Applications

A. Limisiewicz, A. Szynkiewics, and M. Udyrysz, "GPR Survey in urban planning: Recognition of the former cemetery in the area of the current park," 15th International Conference on Ground Penetrating Radar – GPR 2014, pp.103-107, 2014.

J. J. Schultz and M. M. Martin, "Controlled GPR grave research: Comparison of reflection profiles between 500 and 250MHz antennae," *Forensic Sci. Int.*, vol. 209, no. 1–3, pp. 64–69, 2011.

J. J. Schultz, B. S. Walter, and C. Healy, "Long-term sequential monitoring of controlled graves representing common burial scenarios with ground penetrating radar: Years 2 and 3," *J. Appl. Geophys.*, vol. 132, pp. 60–74, 2016.

A. D. Booth and J. K. Pringle, "Semblance analysis to assess GPR data from a five-year forensic study of simulated clandestine graves," *J. Appl. Geophys.*, vol. 125, pp. 37–44, 2016.

H. Dick, J. K. Pringle, R. van der Putten, G. T. Evans, J. Goodwin, K. Wisniewski, J. D. Hansen, and J. Cassella, "Determining geophysical responses from graves," *Geophysics*, 2016.

J. D. Hansen, J. K. Pringle, and J. Goodwin, "GPR and bulk ground resistivity surveys in graveyards: Locating unmarked burials in contrasting soil types," *Forensic Sci. Int.*, vol. 237, pp. e14–e29, 2014.

Geological and Environmnetal Applications

K. Takahashi, J. Igel, H. Preetz, and S. Kuroda, "Basics and Application of Ground- Penetrating Radar as a Tool for Monitoring Irrigation Process," in Problems, Perspectives, and Challenges of Agricultural Water Management, M. Kumar, Ed. InTech, 2012.

N. Allroggen and J. Tronicke, "Attribute-based analysis of time-lapse ground-penetrating radar data," *Geophysics*, vol. 81, no. 1, 2016.

J. Andrade dos Reis Jr, D. Lopes de Castro, T. E. Silva de Jesus, and F. Pinheiro Lima Filho, "Characterization of collapsed paleocave systems using GPR attributes," J. Appl. Geophys., vol. 103, pp. 43–56, 2014.

A. Brovelli and G. Cassiani, "Linking soil properties to permittivity data: Beyond the refractive index model," *C. XVI - Comput. Methods Water Resour. Copenhagen, Denmark, June 19-22 2006*, pp. 1–8, 2006.

N. J. Cassidy, "Evaluating LNAPL contamination using GPR signal attenuation analysis and dielectric property measurements: Practical implications for hydrological studies," 2007.

M. L. Roth, "Sample analysis and modeling to determine GPR capability for mapping fluvial mine tailings in the Coeur d'Alene River channel Open-File Report 96-515," Open-FIle Report 96-515, 1996.

Archaeological Applications

L. B. Conyers and D. Goodman, Ground Penetrating Radar: An Introduction for Archaeologists. Walnut Creek: AltaMira, 1997.

M. Ercoli, R. Brigante, F. Radicioni, C. Pauselli, M. Mazzocca, G. Centi, and A. Stoppini, "Inside the polygonal walls of Amelia (Central Italy): A multidisciplinary data integration, encompassing geodetic monitoring and geophysical prospections," J. Appl. Geophys., vol. 127, pp. 31–44, 2016.

J.T. Smith, Roman Villas: A Study in Social Structure, Ch. 16 "A Model of Development" Routeledge, 1997

S. Castellaro, S. Imposa, F. Barone, F. Chiavetta, S. Gresta, and F. Mulargia, "Georadar and passive seismic survey in the Roman Amphitheatre of Catania (Sicily)," *J. Cult. Herit.*, vol. 9, pp. 357–366, 2008.

F. Boschi, "Geophysical survey of the *Burnum* archaeological site, Croatia," *Archaeological Prospection*, vol.18 ,pp.117-126, 2011.

J.A. Pincus, T.S. de Smet, Y. Tepper, and M.J. Adams, "Ground penetrating radar and electromagnetic archaeogeophysical investigations at the Roman legionary camp at Legio, Israel," *Archaeological Prospection,* vol.20 pp. 175-188, 2013.

Engineering Applications

A. Benedetto and L. Pajewski, Civil Engineering Applications of Ground Penetrating Radar. 2015.

M. Dossi, E. Forte, and M. Pipan, "Auto-picking and phase assessment by means of attribute analysis applied to GPR pavement inspection," 2015 8th Int. Work. Adv. Gr. Penetrating Radar, IWAGPR 2015, pp. 1–4, 2015.

J. White, S. Hurlebaus, P. Shokouhi, A. Wittwer, and A. Wimsatt, "Noncontact techniques for monitoring of tunnel linings," *Struct. Monit. Maint.*, vol. 1, no. 2, pp. 197–211, 2014.

GPR challenges and techniques

W. Neto, Pedro Xavier; Eugenio de Medeiros, "A practical approach to correct attenuation effects in GPR data," J. Appl. Geophys., vol. 59, pp. 140–151, 2006.

M. Dossi, E. Forte, and M. Pipan, "Auto-picking and phase assessment by means of attribute analysis applied to GPR pavement inspection," 2015 8th Int. Work. Adv. Gr. Penetrating Radar, IWAGPR 2015, pp. 1–4, 2015.

Software manuals, guides, and references

GSSI, "SIR System-3000 Manual." Geophysical Survey Systems Inc, Salem, NH, p. 99, 2009.

A. Tzanis, "MATGPR: Release 2 Manual and Technical Reference," Ch 3, pp.37-72. 2010.

A. Ravichandran, "Matlab for the Absolute Beginner," 2011.

C. Xenophontos, "A Beginner's Guide to MATLAB."

GPR_SLICE v7.0: Ground Penetrating Radar Imaging Software User's Manual, 2016

C. Warren, A. Giannopoulos, and I. Giannakis, "gprMax: Open source software to simulate electromagnetic wave propagation for Ground Penetrating Radar," *Comput. Phys. Commun.*, vol. 209, pp. 163–170, 2016.