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NFDI4Objects

Survey Results on Data Management in Geophysical Prospecting

T. Sonnemann, C. Schütze, U.Werban

HELMHOLTZ Zentrum für Umweltforschung

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NFDI4Objects - Survey Results on Data Management in Geophysical Prospecting in Archaeology

Survey Period: 2024/01/12 - 2024/03/31

Authors: T. Sonnemann[1], C. Schütze[2], U. Werban[2]

1 - Universität Bonn, Bonn Center for Digital Humanities
2 - Helmholtz Centre for Environmental Research (UFZ), Department Monitoring and Exploration Technologies

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Content:

0 - General information on survey aims and contents

NFDI4Objects (N4O) is an initiative to establish a multidisciplinary consortium within the National Research Data Infrastructure (NFDI). The initiative is aimed at researchers and professionals whose work focuses on the material heritage of around three million years of human and environmental history and addresses the challenges of modern research data infrastructures. The disciplines covered include not only various archaeologies, but also anthropology, building research, geoarchaeology, archaeobotany and geophysics, among others.

The work program of NFDI4Objects is aligned with the data life cycle of archaeological objects: from exploration and recovery to collection, analysis and preservation of the objects. The storage and dissemination of research data and the transfer of results to education play a central role. The various areas of responsibility are structured into seven task areas (TA). TAs 1-4 in particular address the complex requirements for data management, data documentation and data archiving in the context of collecting and researching primary data sources, scientific object collections and the preservation of cultural monuments.

Geophysical prospecting plays a crucial role in archaeology by providing non-invasive methods to explore and map the subsurface of archaeological sites. Using techniques such as ground-penetrating radar (GPR), magnetometry, electrical resistivity imaging, among others, archaeologists can detect buried structures, artifacts, and features without disturbing the site. This allows for a more comprehensive understanding of the archaeological landscape, helping researchers to plan excavations more effectively and conserve fragile sites. Geophysical prospecting also aids in identifying potential excavation areas, verifying the presence of subsurface features, and monitoring changes in archaeological sites over time. Archaeology has a need for fast and accurate mapping of buried remains, primarily for planning, but also for appropriate alternatives to costly and destructive invasive techniques (Gaffney, 2008). Overall, geophysical prospecting enhances archaeological investigations by providing valuable insights into past human activities while minimizing the impact on cultural heritage.

This questionnaire was developed within TA1 with the aim of gaining an overview of the application of geophysical prospection in archaeology. It was therefore directed in particular at long-standing experts working in this field in research institutions, state offices or commercial companies. The survey was conducted from January to March 2024 and targeted various participant groups in research, industry, and government agencies. It consisted of 56 individual questions divided into six parts: 0. Introduction, 1. Project Planning, 2. Measurement Execution, 3. Data Analysis, 4. Data Visualization, 5. Data Transfer or Archiving in a State Office and 6. Conclusion. Out of 28 invitations sent, 22 experts participated in the survey, yielding a response rate of 79%. Of these, 19 experts fully completed the questionnaire. The results presented here give an overview on the responses by the experts and are indicated with the corresponding question numbering (QXXX).

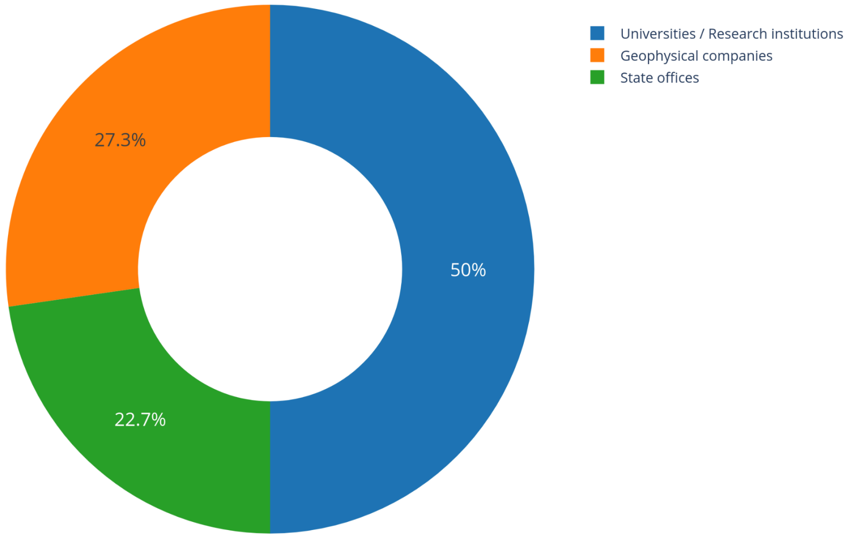

Fig. 0.1: Professional background of the 22 survey participants. The survey response rate was 79 %. *(Source: Q004 - individual information)*

Following a development proposal in an area of high archaeological potential, the state heritage organizations may decide for the necessity of a geophysical survey. If available, it may send its own geophysical survey team (e.g. the state offices of Baden-Wuerttemberg, Bavaria and Saxony-Anhalt, and the regional offices of Rhineland (LVR) and Westphalia (LWL) each have survey teams). These teams work exclusively within their regional boundaries. A second group of experts, at universities or research institutions, may have access to equipment and apply geophysical instruments within their research projects. Alternatively, private companies may be commissioned to perform the survey on demand. They work nationwide, or even abroad, in development and research projects. Representatives of these three groups were approached to take part in the survey. The composition of participants is shown in Fig. 0.1. Due to the variety of professional backgrounds, the analysis of the survey responses has to take into account their different roles as stakeholders in the data management process related to geophysical prospecting in archaeology.

In Germany, the data collected needs to be sent to the regional heritage branch according to the local law, where it is being archived. This particular process, and what it includes in information transfer, will be the concern of NFDI4Objects in terms of the development of harmonized workflows. With the help of the survey data obtained, proposals for standardization in data management within the processes of data acquisition, processing, analysis and archiving are to be developed in line with requirements.

1 - Data management - planning geophysical surveys

- reasons for geophysical prospecting / types of customer / stakeholders
- usage of existent data for planning (sub-questions, aggregation necessary)
- specific guidelines / instructions made by the customer

All matters concerning cultural heritage and archaeology in Germany are organized by the regional states ("Ländersache"), which means that each state has its own heritage laws, its own organization for cultural heritage management and an individual data service. Therefore, the data life cycle from planning an archaeological survey to the way of archiving is independently organized within these official institutions. The collection of geophysical data from archaeological sites may be part of this process. Depending on the motivation for a geophysical survey, as described earlier, different stakeholders are involved with a variety of tasks. The expected work flows may differ.
Many geophysical surveys today are conducted to precede new developments, to set the focus of subsequently planned archaeological excavation; some are commercially oriented, others may have research purposes only (Fig. 1.1).

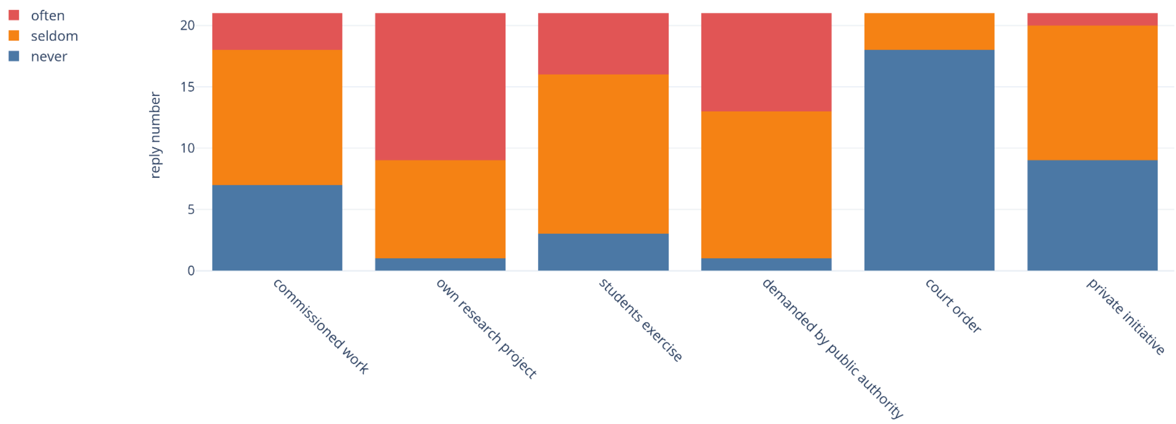

Fig. 1.1: Overview on given answers to the question "*For what purpose are geophysical data, with a focus on archaeology, collected in your institution?" (Source: Q102)*

Most geophysical surveys in archaeology have a research aim, followed in number by a demand from public authorities. Commissioned work is sharply divided into never/seldom (18) and very likely (3), showing the different backgrounds of the representatives interviewed. As this is a general survey on all geophysics in archaeology, not revealing the background of the person is intended. However, clearly student exercises are more likely expected to be the answer from someone at university. German national or state law does not require a geophysical survey to be carried out prior to a development project or to investigate a construction site before the builders arrive, and very seldom, if at all, a survey is demanded by court order.

Target locations for geophysical prospection are, according to the responses, in most occasions already heritage listed sites in the countryside, either on agricultural or fallow land. Less often surveys are performed at construction sites (s.a.), in forests and cemeteries. While surveys are also regularly conducted in urban environments less are performed in the interior of buildings. Barely anyone conducts surveys underwater or in maritime environments, and if so, it happens very seldom.

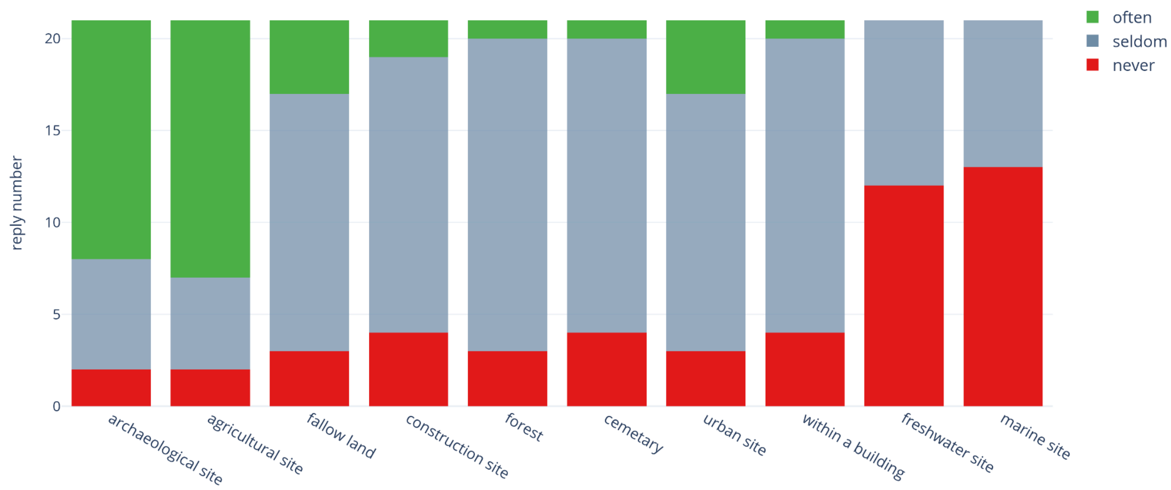

Fig. 1.2: Distribution of typical investigation sites for geophysical prospecting in archaeology. (*Source: Q104*)

The preparation of prospecting tasks often involves the utilization of supplementary information and includes thorough research of external information sources. Question Q105 referred to the application of additional data requested and evaluated for preparation purposes. Frequently mentioned are aerial imagery, LiDAR data, existing archaeological reports, and previously conducted geophysical measurements (Fig. 1.3). Most of the data is open source and publicly available, or asked from and provided by official archaeological services. Less frequently accessed are environmental reports. However, in the open text field, historical maps and sources, geological maps, soil maps, satellite imagery, as well as subsurface utilities and cadastral plans were additionally mentioned as other sources by the participants.

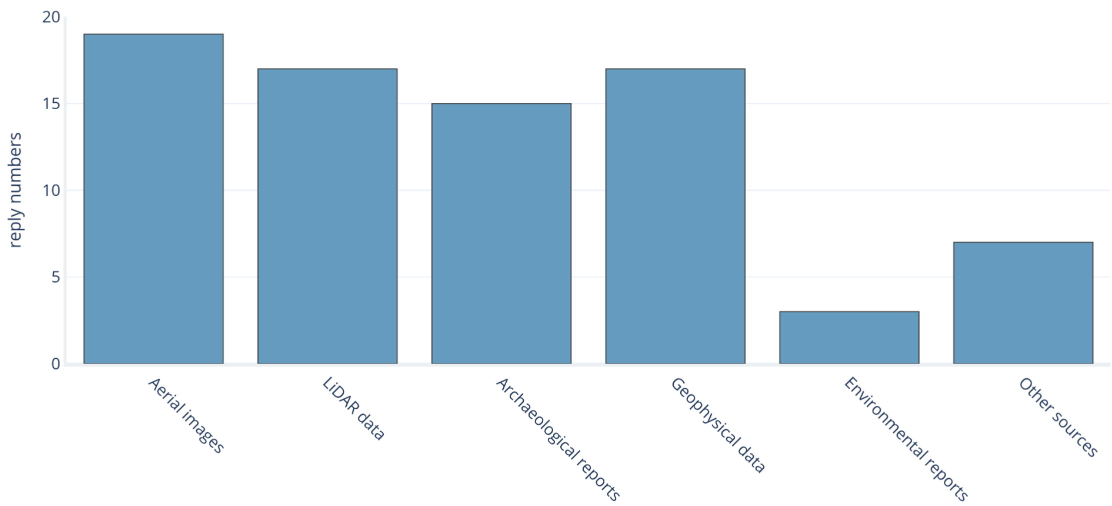

Fig. 1.3: Preparation of geophysical prospecting is often based on the usage of already existent supplementary data. (*Source: Q105*)

The last question in the planning section concerned the given standards describing the conductance, analysis and archival of geophysical measurements used for the preparation phase. The responses highlighted the lack of a clear standardized workflow available for the preparation of geophysical prospecting for archaeological questions. Several mentioned specifications were based on guidelines given by the state and regional heritage authorities.

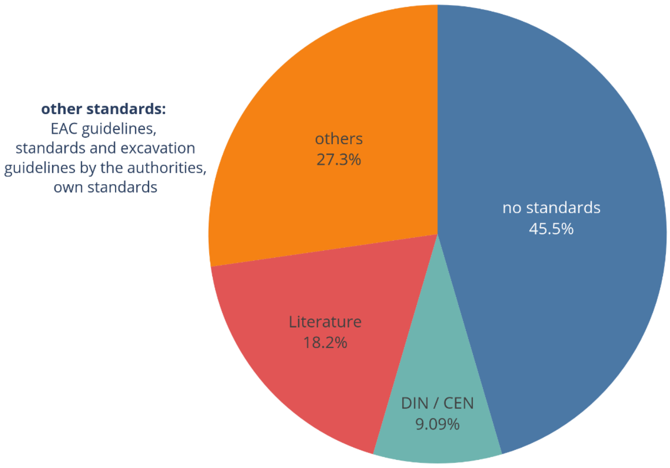

Fig. 1.4: Survey response on given specifications and standards in terms of conductance, analysis and archival of geophysical prospecting in archaeology. Standards listed in the “others” section can be found in the references of the report. (*Source: Q107*)

2 - Data management - conductance of geophysical measurements

- Frequency plot of applied geophysical methods
- specific reasons why to use … magnetics / GPR (as example)
- commonly used metadata
- established standards

For the sequence of methods being applied to answer an archaeological question (Q201), the order of use starts with GPR and magnetics followed by geoelectrical methods. About half of the interviewees apply electromagnetic induction (EMI) and only a few implement seismics. Regarding the frequency of instruments in use in a geophysical prospection survey, the outcome is dominated by the magnetic survey, followed by ground-penetrating radar and geoelectrical methods.

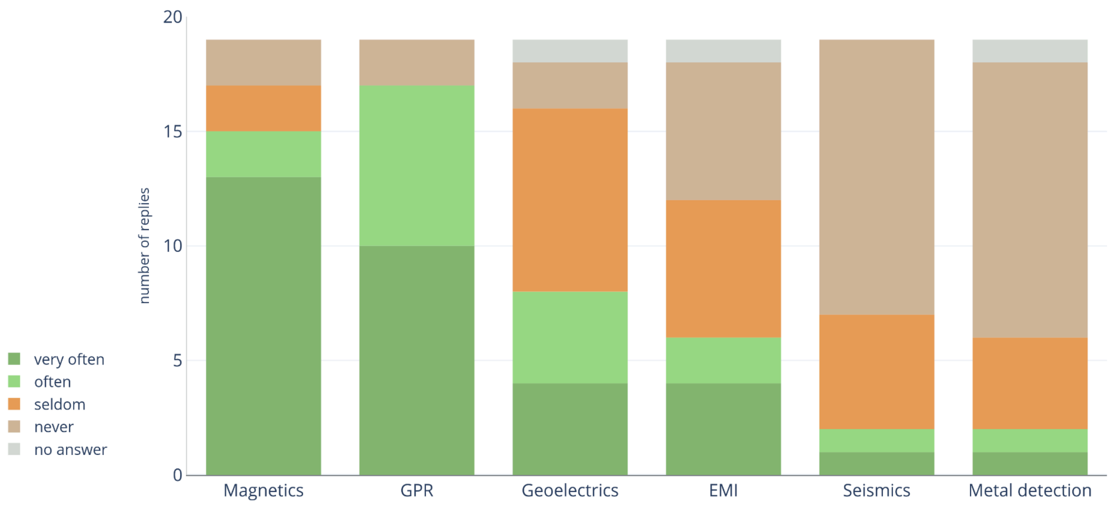

Fig. 2.1: Distribution of frequently used geophysical methods for archaeological investigations. (*Source: Q201*)

Rationale for a geophysical survey is, according to the study, often driven by the need for a fast, mostly non-invasive and less-destructive technique, or a fast surveying method for large areas using *multi-sensor* systems. An interesting fact was derived from a detailed consideration of the personal answers to question Q201: while the state offices only reported magnetics and georadar as applied methods, companies and research institutions also often indicated other prospecting techniques as "commonly used". Having or not having easy access to an instrument is for every method also a major decision factor. The main reason for deciding to conduct a magnetic survey is the otherwise unmatched recording speed. While multi-sensor systems also exist for GPR and geoelectrical methods, neither instrument reaches comparable coverage. The decision to pick GPR as often as magnetics is also driven by the expected size and type of the archaeological finds. Much less likely to be picked are geoelectrical methods. The main reason for latter use is target depth, likely here to find a particularly deeper object, structure or soil horizon, which apparently is also a reason for applying GPR. Barely anyone applies seismics or metal detectors in their line of work, and seldom if at all electromagnetic equipment.

The answers given need to be understood by the availability and accessibility of equipment. If a team is focused on archaeological prospection, it may have only access to particular geophysical survey equipment. In comparison, a geophysics company or a larger research facility may have a diverse range of instruments for research questions beyond archaeo-geophysics, which could potentially also test a method at an archaeological site.

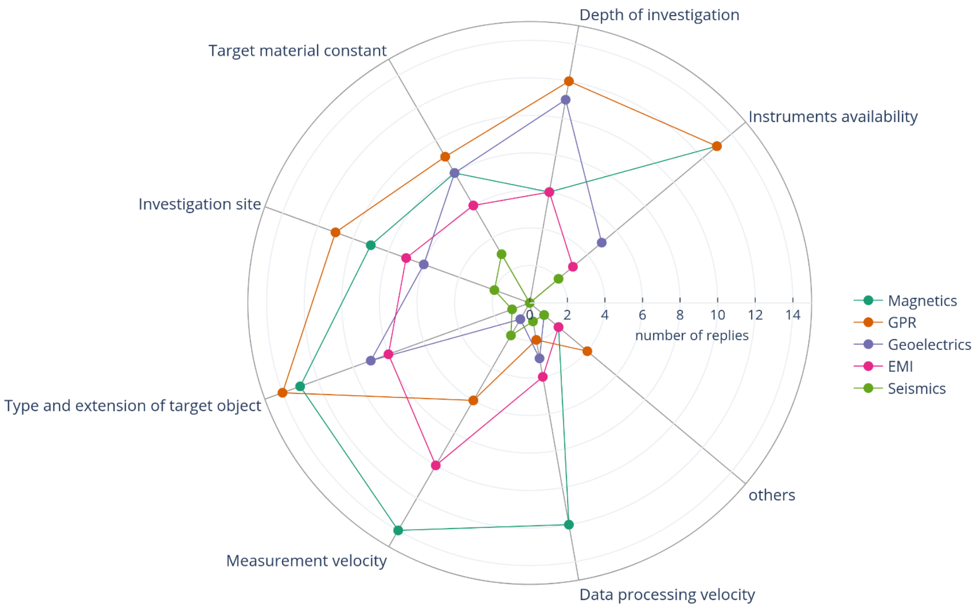

Fig. 2.2: Driving factors for the selection of the various geophysical prospecting methods. *(Source: Q203)*

Additional, more specific questions (Q203 and Q204) on the particular survey design of a specific method followed, when the frequency of use picked was at least “regularly”. The answers given provide initial insights into the common handling of these techniques. The questions targeted, for example, the spacing of single recording points in walking direction and between survey lines, or spacing of electrodes in electric resistivity surveys. This information would be part of the metadata, necessary to possibly recreate the survey from the raw files.

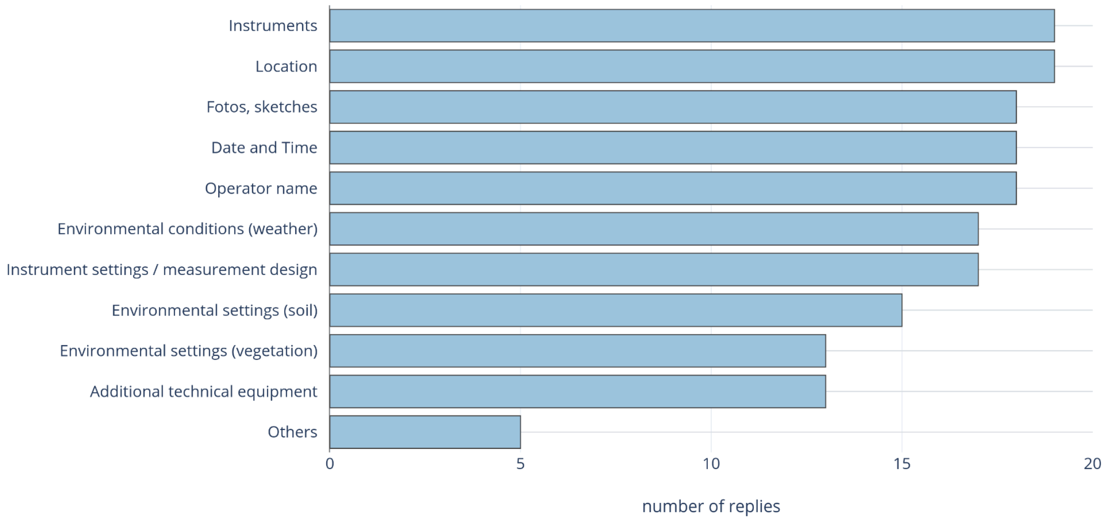

Fig. 2.3: Important information gathered on-site during the measurement campaign. *(Source: Q205)*

A follow up question (Q205) asked about any additional information collected on top of the raw measurement data (Fig. 2.3). All replies included the specification of the used instrument and the location where the data was collected, followed in number by the date of survey and name of the operator, as well as photos and sketches of the location. Information on environmental conditions such as weather, soil and vegetation are also frequently included. In the "Others" section the participants added special incidents, 3D coordinates of the measuring points and the location of the GPS base.

The last question Q206 in this survey section considered the known and applied standards to conduct geophysical measurements for archaeological tasks. Here, a similar pattern as in question Q107 was observed. 48 percent of participants stated that there are no established standards for each method and that they do not use standards. If standards are used, applicants have referred to DIN (14%), EAC-Guidelines for the Use of Geophysics in Archaeology (Schmidt et al., 2015) (24%) or prospecting and excavation guidelines of the state offices (e.g. Linck & Stele, 2023) (14%).

3 - Data management - analysis and evaluation of geophysical measurement data

- Software
- Documentation
- established standards

Our interest was also to find out about the current knowledge regarding standards, and which of them are applied within the work progress. While standards are being followed in citing literature, the common German or European official standards DIN/CEN, ISO or VDI are not being followed. Even less follow a standard procedure when it comes to processing. The reason for this could be that there is no general software for processing geophysical data, but different options for each method. Sometimes even the instrument brand defines the software used, as it was provided with the buy. Regarding magnetics data, in-house software is the use of choice, followed by commercial solutions (Surfer & Magneto). GPR processing in Germany is dominated by commercial solutions, most use ReflexW (14), a lesser number use GPR Slice and Radan (each 4) but there are an equally small number with in-house software. For geoelectrical methods the open source software package BERT-pyGIMLi has the most uses, followed by the commercial Res2Dinv. 18 percent of the interviewees also use in-house software. For the less implemented electromagnetics in-house processing software leads with Surfer; GIS Emagpy and Aarhus Workbench combining more than half of the remaining uses. The few seismic surveys conducted in archaeology are processed with in-house software, ReflexW and RadEx trailing behind.

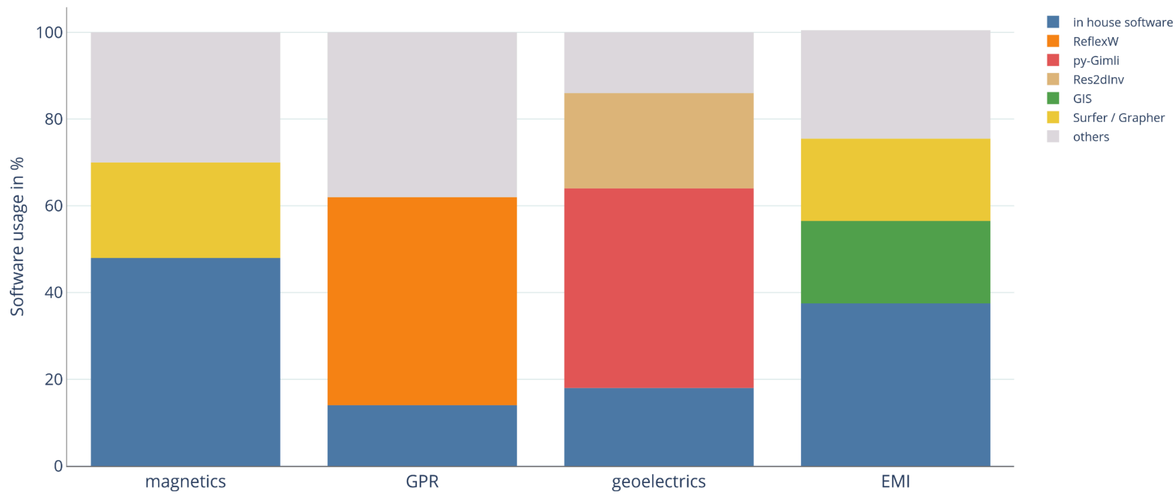

Fig. 3.1: Percentage of software used for measurement data processing. *(Source: Q302)*

In question Q303 the survey participants were asked to list the information which is documented and archived internally. In addition to the processing steps, the processing parameters and the software used are often filed. It is noticeable that information on QA/QC is stored less frequently (Fig. 3.2). When asked Q304 about standards for data processing, almost all participants stated that apart from a few literature references (e.g. Schmidt et al., 2015), no further standards exist. However, this survey showed that there are established software modules and routines for data processing for some methods (e.g. GPR, geoelectrics). Less standardized evaluations are to be expected with in-house data processing programs.

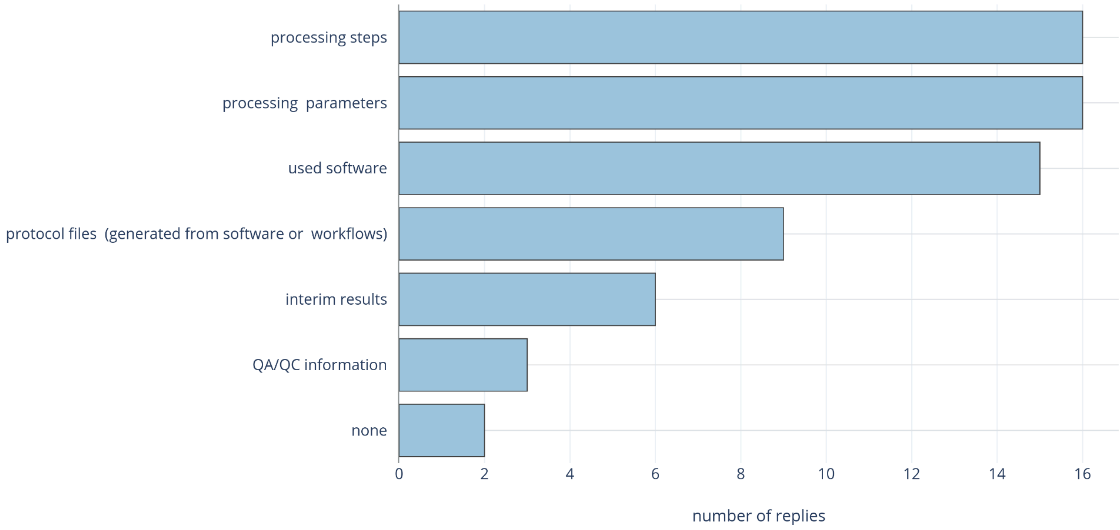

Fig. 3.2: Important information which is documented and archived internally. *(Source: Q303)*

4 - Data management - visualisation of geophysical data

- visualisation tools
- already existent standards

Question Q401 is related to common software tools regarding data visualization. The predominant program for the visualization of geophysical data is (Q)uantum GIS, an open source software package for geographic information systems. The most common commercial option ESRI ArcGIS is much less applied. A number of users have developed their own software, reasoning it with the need for mapping of measurements, transformation of results or interpretation and merging the results from different instruments. Different programs offer the possibility to integrate and compare a variety of heterogeneous data sets, that may be from geophysics as well as archaeology.

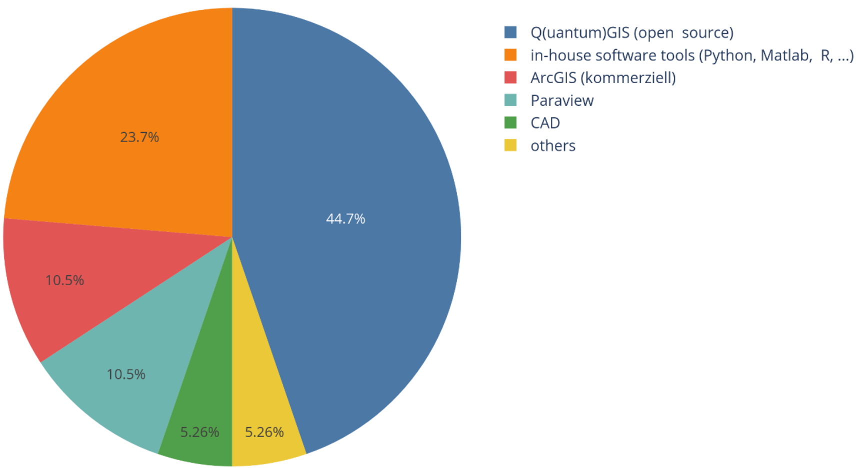

Fig. 4.1: Percentage of 2D-data visualisation tools. (*Source: Q401*)

Almost all data visualization tools are used to spatially display the final results in the form of maps and plans. The representation as georeferenced data sets plays an important role in the answers given. However, most GIS software visualizations are limited to two dimensions, which prevents the display of height or depth, essential for various geophysical applications. Commercial software CAD, the open-source alternative Paraview and in-house software tools offer these functionalities and are used to close this gap for the visualization of 3D data (Q402).

The collective answers to question Q403 show that no visualization standards have yet been established in the archaeo-geophysical community.

5 - Data management - data transfer and archiving

- kind of reports and data / metadata compilation for customers
- established standards

In part 5 the participants were asked to comment on common practises in data management, particularly referring here to data transfer to and archival of results at the state offices. The answers display that the digital format has become the predominant standard for reporting. However, still a large number of reports are being handed in with an additional printed version.

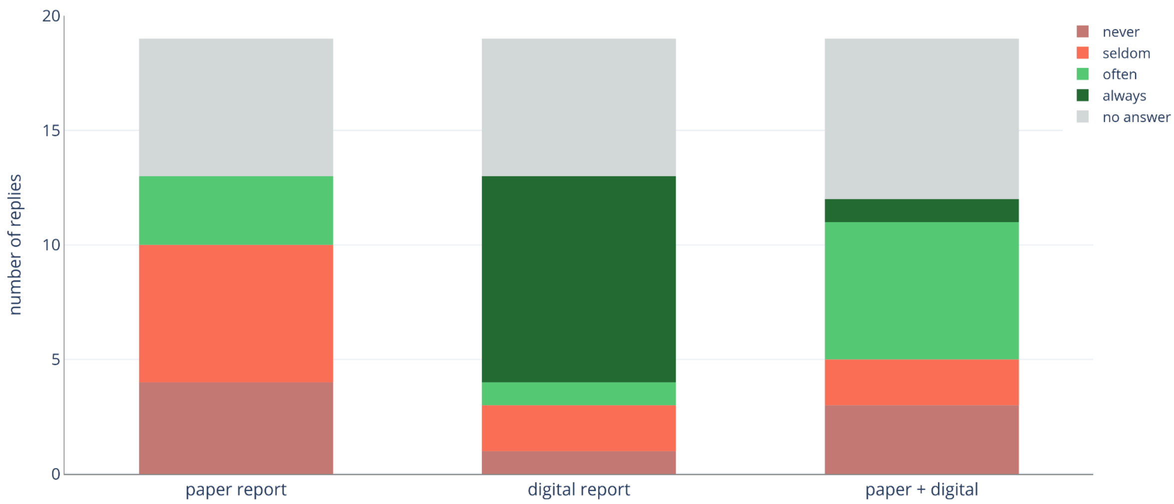

Fig. 5.1: Distribution of common handling in terms of report type. (*Source: Q501*)

Questions Q508 and Q511 target the knowledge and implementation of existing standards in archiving data and metadata. The feedback reveals a significant lack of uniform practices. Data archival is primarily based on the excavation and prospection guidelines of the individual state and regional heritage offices. Without federal law the requirements differ in each state. Rules or guidelines often only contain predefined folder structures in the filing / archive system. Some metadata standards (Dublin Core, INSPIRE, FairSharing.org) are mentioned, but by fewer than 20% of the respondents. However, it is common practice to provide metadata in the form of a supplementary text or report.

In question Q509, the participants were asked about the data that is finally handed over to the client for archiving. The client for whom the data was collected could be a private organization or a state or regional office. The clients mostly (70%) expect derived and visualized data which explains the survey results. Raw data is provided in four out of 10 cases. 30% of clients also expect QA/QC data. A few respondents offer only the archaeological interpretations derived from the geophysical measurement results in the form of drawings.

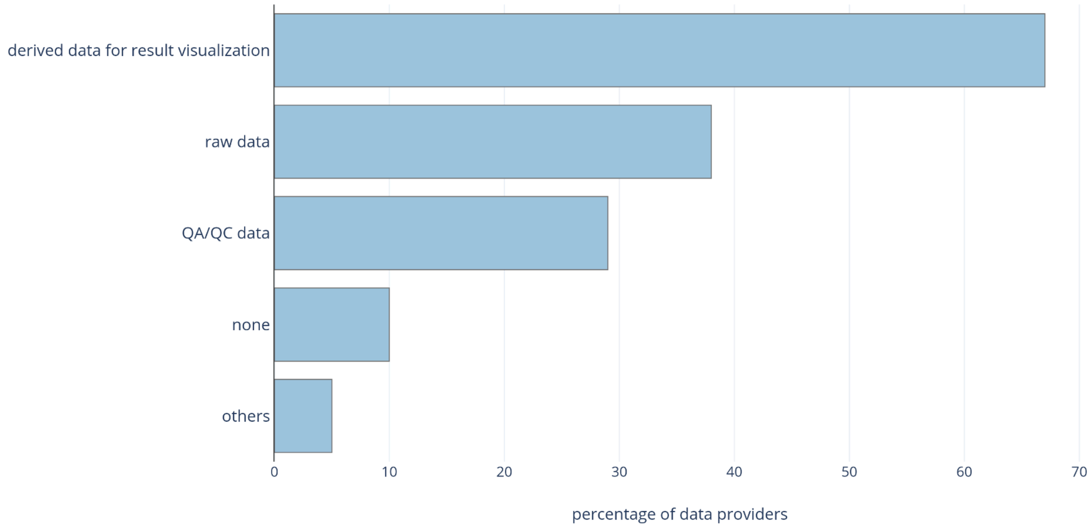

Fig. 5.2: Percentage of data provided to the clients. *(Source: Q509)*

An interesting aspect arises from question Q510, which asked about the most common data formats. The responses indicate that ASCII format files (CSV) constitute 40%, and Excel format files constitute 16%, representing the clear majority. These formats therefore offer sustainable usability. Additionally, specific formats generated by geophysical devices or software are also common (28%). In particular, GPR and seismic methods utilize industry-standard formats such as binary SGY or SG2 (12%) for profile data. New flexible formats such as XML or JSON have not yet been established and are not currently used to any significant extent by any of the participants.

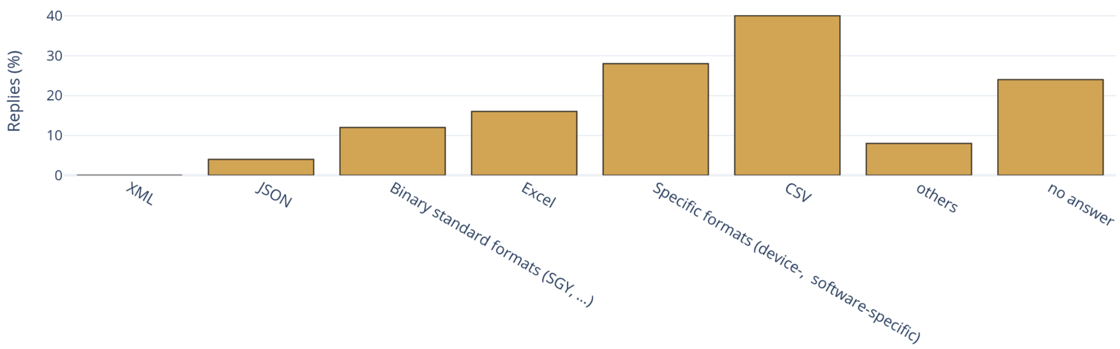

Fig. 5.3: Percentage of used data formats. *(Source: Q510)*

6 - Data management in geophysical prospecting - perspectives, exploitation and dissemination

- evaluation of results and resulting tasks
- conclusions and outlook - what is planned based on the study results
- thank to participants

In archaeology, geophysical surveys are carried out by a variety of people, generally geophysicists, but due to the transdisciplinary work also by people with other professional backgrounds and expertise. Someone may not have studied the techniques at university but learned it in practical use in the field, as part of an archaeological or geotechnical survey. Independent from the knowledge of the survey conductor, the data collected needs to be archived in a form that is still accessible and the results must be reproducible even years or decades later. This asks for a broadly accepted and widely used open-source format readable by machine and humans, and setting minimum requirements for metadata.

The survey provides a detailed insight into the practical geophysical prospecting work across the different stakeholders involved in the investigation of cultural heritage. The results point out, there are various established standards for the application of geophysical methods for archaeological tasks, and several sources have also been named here. However, they also show that most participants follow individual principles to manage, share and store data. These data management systems are either provided by the regional archaeological heritage management office or were designed on a personal basis for the individual needs. Some heritage offices have created guides on how to handle the data.

The main tasks arising from the survey are as follows:

(1) A detailed analysis of existing sources of geophysical data management standards is required in order to develop and recommend best practices along the whole data life cycle.

(2) There is a need to discuss and agree on a terminology / ontology for processes in the complete data cycle. For archival purposes there is a need for transdisciplinary harmonization and further development of common vocabularies. Particularly on data collection and processing terminology a collaboration is planned with topic-related groups at NFDI4Earth. Regarding the vocabulary in archaeological data interpretation, the community cluster will contribute to the developments made within NFDI4Objects.

(3) There is a broad consensus concerning the harmonization of metadata contents and formats. Existing standards need to be promoted and implemented; a framework for core metadata elements has to be developed. This also has to be done in close collaboration with sister communities in German National Research Data Infrastructure NDFI.

(4) The different geophysical methods applied in archaeology require individual format solutions for archival. Here, geophysical 2D data demands a different storage structure than 3D data.The same applies to data where georeferencing happens automatically in the field, compared to subsequent orientation of results after post-processing. In addition, there is a discussion on the distinction between archivable and archive-worthy data. Existing options for data formats already designed by members of the community cluster

will be tested and discussed. Perspectively, the ultimate goal will be to provide a guide for each relevant method. Previously unused solutions such as Extensible Markup Language (XML) are able to represent hierarchically structured data in a text file format, readable by both humans and machines and offers a flexible and structured way to store data, making it ideal for data archiving. Its ability to maintain complex data hierarchies and metadata ensures long-term accessibility and interoperability across different systems.

The questionnaire, as well as the literature overview shows that available solutions are already in use. The goal of the NDFI is to harmonize these solutions for an equal standard of geophysical prospection.

Our intention was not only to address archaeo-geophysical experts in Germany to complete the questionnaire in order to determine the current status in geophysical prospecting, but also to raise awareness and to encourage participation in a NFDI4Objects Community Cluster addressing these issues. With overall very positive responses by the participants, the NFDI4Objects Community Cluster Geophysical Prospection was initiated in May 2024. The cluster first met officially in two sessions in July 2024 where the predominant issues addressed in the survey were highlighted in lively discussions.

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Dipl. geophys. Ulrich Burkart (Eastern Atlas GmbH & Co. KG)

In addition, the authors also completed the survey.

7 - References / Further Reading

- Archaeological Data Service, https://archaeologydataservice.ac.uk/ (access 22.07.2024)
- Gaffney, C. (2008): Detecting trends in the prediction of the buried past: A review of geophysical techniques in Archaeology. Archaeometry, 50: 313-336. https://doi.org/10.1111/j.1475-4754.2008.00388.x
- Forschungsdatenzentrum Archäologie und Altertumswissenschaften IANUS, https://ianus-fdz.de/ (access 22.07.2024)
- James SR, Foks NL and Minsley BJ (2022): GSPy: A new toolbox and data standard for Geophysical Datasets. Front. Earth Sci. 10:907614. https://doi.org/10.3389/feart.2022.907614
- Linck, R., Stele, A. (2023): Standards zur Durchführung geophysikalischer Prospektion in der Archäologie in Bayern. Bayerisches Landesamt für Denkmalpflege, 6 S. https://www.blfd.bayern.de/mam/abteilungen_und_aufgaben/denkmalforschung_und_denkmalerfassung/zentrallabor/standards_geophysikalische_prospektion_2023_09.pdf
- LVR-Amt für Bodendenkmalpflege im Rheinland (2020): Prospektions- und Grabungsrichtlinien für archäologische Maßnahmen. 106 S. https://bodendenkmalpflege.lvr.de/media/bodendenkmalpflege/service/pdf_3/Grabungsrichtlinien_2020.pdf
- LWL-Archäologie für Westfalen (2023): Grabungsrichtlinien für archäologische Maßnahmen in Westfalen-Lippe. https://www.lwl-archaeologie.de/media/filer_public/2c/fe/2cfe3b94-ac59-48f4-9202-555b3f165987/lwl_grabungsrichtlinien_maerz_2023.pdf
- Niedersächsisches Landesamt für Denkmalpflege (2017): Richtlinien zur Dokumentation archäologischer Maßnahmen / Ausgrabungen. https://denkmalpflege.niedersachsen.de/download/110131/Richtlinien_zur_Dokumentation_Archaeologischer_Massnahmen_Ausgrabungen_in_Niedersachsen_August_2017.pdf
- Schmidt AR, Linford P, Linford N, David A, Gaffney CF, Sarris A and Fassbinder J (2015): EAC Guidelines for the use of Geophysics in Archaeology: Questions to Ask and Points to Consider. EAC Guidelines 2. Namur, Belgium: Europae Archaeologia Consilium (EAC), Association Internationale sans But Lucratif (AISBL). ISBN 978-963-9911-73-4. 135p. https://bradscholars.brad.ac.uk/handle/10454/8129
- Verband der Landesarchäologen in der Bundesrepublik Deutschland (2006): Ausgrabungen und Prospektion, Durchführung und Dokumentation. Archäologisches Nachrichtenblatt 4 (1999), Heft 1 / Überarbeitete Fassung, Stand 03.04.06. 65 S. https://www.landesarchaeologien.de/fileadmin/mediamanager/004-Kommissionen/Grabungstechnik/Grabungsstandards/grabungsstandards_april_06.pdf