remote sensing

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Conference Report

Sensing Archaeology in the North: The Use of Non-Destructive Geophysical and Remote Sensing Methods in Archaeology in Scandinavian and North Atlantic Territories

Carmen Cuenca-García [1,*], Ole Risbøl [1], C. Richard Bates [2], Arne Anderson Stamnes [1], Fredrik Skoglund [1], Øyvind Ødegård [1], Andreas Viberg [3], Satu Koivisto [4], Mikkel Fuglsang [5], Manuel Gabler [6], Esben Schlosser Mauritsen [7], Wesa Perttola [8] and Dag-Øyvind Solem [6]

1 Department of Archaeology and Cultural History, NTNU University Museum, Norwegian University of Science and Technology (NTNU), Erling Skakkes gate 47B, 7012 Trondheim, Norway; ole.risbol@ntnu.no (O.R.); arne.stamnes@ntnu.no (A.A.S.); fredrik.skoglund@ntnu.no (F.S.); oyvind.odegard@ntnu.no (Ø.Ø.)
2 School of Earth and Environmental Sciences, University of St Andrews, St. Andrews, Fife, St Andrews KY16 9AJ, UK; crb@st-andrews.ac.uk
3 Guideline Geo-Malå/ABEM, SE-172 66 Sundbyberg, Sweden; andreas.viberg@guidelinegeo.com
4 Department of Archaeology, University of Turku, FI-20014 Turku, Finland; satu.sa.koivisto@utu.fi
5 Midtjylland Museum, 7400 Herning, Denmark; mf@museummidtjylland.dk
6 Norwegian Institute for Cultural Heritage Research, 0155 Oslo and 7013 Trondheim, Norway; manuel.gabler@niku.no (M.G.); dag-oyvind.engtro@niku.no (D.-Ø.S.)
7 Department of Archaeology, Ringkøbing-Skjern Museum/ARKVEST, 6900 Skjern, Denmark; esm@arkvest.dk
8 Department of Cultures/Archaeology, University of Helsinki, 00014 Helsinki, Finland; wesa.perttola@helsinki.fi
* Correspondence: carmen.cuenca-garcia@ntnu.no

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Abstract: In August 2018, a group of experts working with terrestrial/marine geophysics and remote sensing methods to explore archaeological sites in Denmark, Finland, Norway, Scotland and Sweden gathered together for the first time at the Workshop 'Sensing Archaeology in The North'. The goal was to exchange experiences, discuss challenges, and consider future directions for further developing these methods and strategies for their use in archaeology. After the event, this special journal issue was arranged to publish papers that are based on the workshop presentations, but also to incorporate work that is produced by other researchers in the field. This paper closes the special issue and further aims to provide current state-of-the-art for the methods represented by the workshop. Here, we introduce the aspects that inspired the organisation of the meeting, a summary of the 12 presentations and eight paper contributions, as well as a discussion about the main outcomes of the workshop roundtables, including the production of two searchable databases (online resources and equipment). We conclude with the position that the 'North', together with its unique cultural heritage and thriving research community, is at the forefront of good practice in the application and development of sensing methods in archaeological research and management. However, further method development is required, so we claim the support of funding bodies to back research efforts based on testing/experimental studies to: explore unknown survey environments and identify optimal survey conditions, as well as to monitor the preservation of archaeological remains, especially those that are at risk. It is demonstrated that remote sensing and geophysics not only have an important role in the safeguarding of archaeological sites from development and within prehistorical-historical research, but the methods can be especially useful in recording and monitoring the increased impact of climate change on sites in the North.

Keywords: remote sensing; near-surface geophysics; archaeological geophysics; marine archaeology; archaeological prospection; aerial archaeology; cultural heritage management; LiDAR/airborne laser scanning (ALS); photogrammetry; unmanned aerial vehicle (UAV)/drone mapping; underwater robotics; side-scan sonar (SSS); synthetic aperture sonar (SAS); underwater hyperspectral imaging (UHI); magnetometry; earth resistance/resistivity; electromagnetic induction; ground-penetrating radar (GPR); reflectance transformation imaging (RTI); image-based modelling (IBM)

1. Introduction

Airborne laser scanning (ALS or LiDAR hereafter), satellite imagery, terrestrial (or ground-based) geophysical prospection, or marine geophysics, inter alia, currently stand as powerful methods in archaeology to remotely find and study sites (i.e., from the ground surface, from the sea, or from the air) in a non-destructive and minimally invasive manner. In the last decades, major technological developments have introduced smaller and more compact sensors, sensor arrays or multi-channel systems, and motorised or robotised ground, aerial and marine platforms, and related software that are opening new frontiers in archaeological research. These breakthroughs have allowed for the implementation of extremely fast and high-resolution surveys to discover and explore sites that are located in remote terrestrial and marine environments. The consequent progress in field methods and strategies is expanding the horizons for archaeological applications at both a site and archaeo-landscape level [1,2].

Many of the sensing technologies have been tested, and some have been developed in Nordic countries. For example, this has been the case with ground-penetrating radar (GPR), low-frequency electromagnetic induction, and electrical resistivity instrumentation. In Sweden, the instrument manufacturer ABEM (Aktiebolaget Elektrisk Malmletning) was founded in 1923 and they initially created electrical resistivity instruments for the detection of iron ore. The Swedish Geological Survey (SGU) launched a research program in the small community of Malå (Sweden) to develop instruments for ore body prospecting in 1936. They developed an electrical conductivity meter (slingram) and, from 1982, GPR equipment for borehole explorations. Malå Geoscience was created by former SGU employees in 1993 and, in 1994, they released their first surface radar system (Malå RAMAC). Both Malå and ABEM are now part of the Swedish Guideline Geo. In Norway, a new generation step-frequency GPR multichannel system was developed at the Norwegian University of Science and Technology (NTNU, Trondheim) and founded as a spin-off company in 2001 (3D Radar).

The potential in the application of sensing methods in archaeology has been realised by the EU and several major international research and networking projects have been granted under the Culture 2007–2013 or Horizon 2020 frameworks, including *ArchaeoLandscapes Europe (ArcLand)* [3], *COST Action SAGA* [4] and *ERC Europe's Lost Frontiers* [5].

The technological momentum and showcased research and projects achieved so far have stimulated increased attention to these technologies by cultural heritage management institutions and other stakeholders everywhere in Europe, but especially in northern countries. In the case of Norway, this attention has been manifested in a major investment in infrastructure and personnel to equip several CH management and research institutions. This flourishing 'Nordic' scenario inspired the organisation of the *Sensing Archaeology in the North (SAN)* workshop and creation of the *SAN* network.

2. The Sensing Archaeology in the North Workshop

The workshop was organised by the 'TErrestrial, Marine, and Aerial Remote sensing for archaeology' (TEMAR) research group at the Department of Archaeology and Cultural History (University Museum, Norwegian University of Science and Technology—NTNU) during 29–30 August 2020. 13 researchers with interests in the application of terrestrial (i.e., ground-based sensors), marine, and aerial/remote sensing methods for archaeological investigations attended the activity (Figure 1). The goal was to bring together different groups, covering a representative range of northern territories and disciplines, in order to promote an initial discussion arena. In doing so, the objectives were to understand the current situation in each country, learn from each other's experiences and visualise, together, a future path for increased development.

Figure 1. Participants of the workshop '*Sensing Archaeology in the North*'. From left to right: Esben Schlosser Mauritsen (Denmark), Dag-Øyvind Solem (Norway), Mikkel Fuglsang (Denmark), Arne Anderson Stamnes (Norway), Andreas Viberg (Sweden), Manuel Gabler (Norway), Ole Risbøl (Norway), Øyvind Ødegård (Norway), Carmen Cuenca-García (Norway), Satu Koivisto (Finland), Wesa Perttola (Finland), Richard Bates (Scotland), Fredrik Skoglund (Norway). Photo by Raymond Sauvage, NTNU University Museum.

The format consisted of a series of presentations during the mornings by the invited participants, who provided overviews about the current status of the different technologies, as well as a number of illustrative case studies. Based on the overviews, two afternoon roundtable sessions focused discussions on: the current use and challenges of these methods in research and cultural heritage management, and future directions.

3. Workshop Presentations and Special Issue Papers

During the first day of the workshop, the presentations focused on providing several national overviews on remote sensing methods and ground-based geophysical surveying.

The workshop started with the talk ***'LiDAR in Norwegian archaeology—research, development and utilisation'*** by Ole Risbøl. This was a perspective of how LiDAR has been adopted for archaeology in Norway and included a presentation of the contributions by various Norwegian researchers and research institutions towards LiDAR research and development. Risbøl explained how LiDAR first emerged, two decades ago, as a potential method in archaeology until it was used in the first archaeological project in Norway in 2005, becoming one of the first pioneering projects, and providing immediate good results. Risbøl described that the bulk of LiDAR research in Norway has focused on how well-suited LiDAR is for identifying, mapping and documenting archaeological features in outfield land and mainly in forested areas (Figure 2). This has led to various statistical studies assessing, for instance, the detection success rates related to laser pulse density as well as size and shape of the targeted features [6,7]. Substantial research has focused on the development of algorithms for semi-automatic detection of archaeological features in LiDAR data, including machine learning as an alternative to human desk-based visual analyses and interpretations. He discussed other approaches, such as the combination of historical aerial photos and recent LiDAR data for monitoring studies; the use of digital terrain models that are generated from LiDAR data and view-shed analysis; and, the assessment of the efficiency of LiDAR to uncover archaeology on a landscape scale. Risbøl ended his talk highlighting the most recent development in LiDAR research: the development and testing of drone-mounted LiDAR.

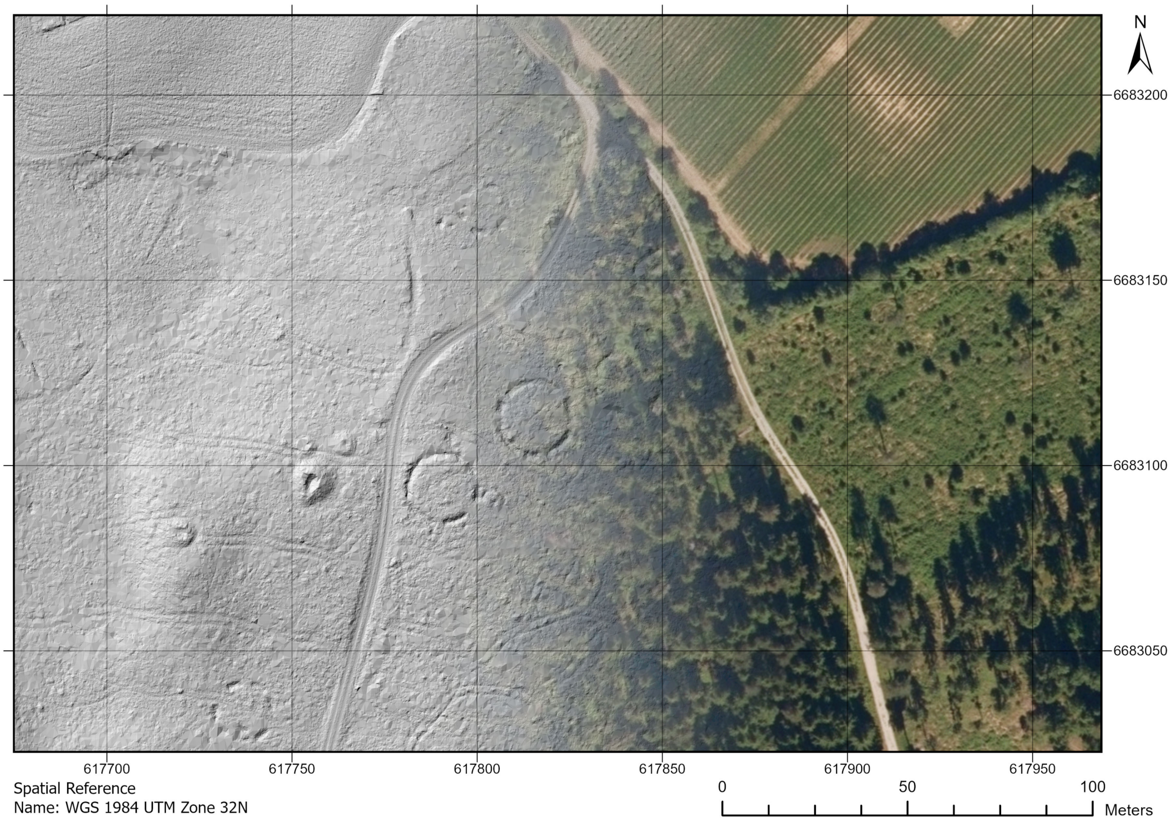

Figure 2. A landscape section from a rural district north of Oslo in SE-Norway seen from aloft. The right-hand part of the image is an aerial photo and the left-hand part a LiDAR generated digital terrain model. The image exemplifies a forest holding a large number of cultural features, in this case charcoal kilns, grave mounds and (hollow) roads. Illustration by Magnar Mojaren Gran, NTNU University Museum.

The Norwegian perspective on LiDAR that was provided by Risbøl during the workshop was followed by a comprehensive review paper on the use and development of LiDAR in Norway, but including also Denmark, Sweden, and Finland, which has been published in the special issue [8]. Here, Risbøl et al. elaborate on the aspects that he discussed in the workshop, addressing other aspects, such as the increasing and successful use of LiDAR in community archaeology and outreach. The authors conclude that, despite the use of LiDAR in Fennoscandia having been used more for cultural heritage management purposes than investigating archaeological-related questions about the human past, this situation may change when considering the experiences in other regions across the world, for example, in Mesoamerica and Southeast Asia [9,10]. Additionally, knowledge gaps to be considered by Northern researchers include exploring the integration of LiDAR intensity data and bathymetrical laser scanning, along with the inevitable further development of drone-based LiDAR.

The presentation by Esben Schlosser Mauritsen titled ***'An aerial view of the past: 10 years of aerial archaeology in Denmark'*** outlined the activities and results of a national project coordinated by Holstebro Museum [11]. Mauritsen explained that whilst the core activity has been basic investigation of existing aerial photography (Figure 3) and LiDAR, several sites have been investigated while using multiple sensing techniques and he showcased these cases. He also discussed the results of commissioned high-resolution LiDAR data that were obtained from the difficult-to-access densely forested pine plantations of West Jutland. Mauritsen concluded that all of these efforts have resulted in the discovery and recording of more than a thousand cropmark sites, mostly large prehistoric settlements, and several thousand soilmark sites, mainly burial mounds. These experiences have also resulted in an overall improvement in the understanding of cropmarks, soilmarks, and earthworks in Danish aerial archaeology, which has also been largely facilitated by integrating different methods for data validation. These included test-pitting but also less invasive methods such as field walking or geophysical surveys. All of the geophysical surveys were carried out in cooperation with international institutions (i.e., CAU Kiel and the Ludwig Boltzmann Institute for Archaeological Prospection and Virtual Archaeology-LBI ArchPro) [12].

Figure 3. Positive cropmarks revealing a remarkably sized longhouse from the early Bronze Age located in Frihedsminde, Central Jutland, Denmark. It measures 40 by 8.5 m and covers no less than 320 square meters. Photo by Lis Helles Olesen, Holstebro Museum.

Satu Koivisto and Wesa Perttola contributed with the presentation ***''The application of remote sensing techniques in Finnish archaeology in brief—experiences, trends, and challenges'***. The authors provided a review of the experiences and trends in the application of remote sensing techniques in Finnish archaeology as well as pressing issues affecting the profitable use of these techniques in both research-based investigations and cultural heritage management. They described LiDAR, with its capacity to filter vegetation, as being the most successful remote sensing method in the detection and management of Finnish archaeological sites, which contain earthwork features. The reason for this is that 73% of the land area of Finland is covered by boreal forest (except the treeless zone of Northern Lapland), a characteristic that has hindered the use of other remote sensing methods (e.g., aerial reconnaissance or satellite imagery) to image the more than 60% of archaeological sites estimated to be situated under forest cover. They argued that changes in vegetation and environment also cause problems in reconstructing former landscapes and selecting the areas of potential for archaeology. For example, shore-bound hunter-gatherer sites are currently situated deep in the inland forests due to rapid postglacial rebound, which is at its strongest in western Finland. Whilst covered by dense vegetation, their identification via traditional field survey and prospection has been challenging and

LiDAR has provided a solution for their prospection [13] (Figure 4). Another type of archaeological site described by the authors as being in urgent need to be explored and recorded ia those concealed in paludified and submerged environments. Side-scan sonar (SSS), GPR and multi-beam echo sounder (MBES) have been successfully used when wrecks and other underwater structures (e.g., stone built fish weirs) have been sought in seabed and lake environments [14]. However, the detection of prehistoric submerged sites affected by, for instance, transgressions and flooding (and consequently covered by thick sedimentation), as well as those submerged in shallow waters, represent a challenge to sensing methods [15]. In addition, ground-based geophysical surveys conducted in waterlogged environments have most typically failed when too small-scale and too deeply buried remains have been pursued [16]. The pilot project *Lost Inland Landscapes* coordinated by the University of Helsinki (2015 and 2017–2018) aimed to detect submerged and paludified Mesolithic sites in lake environments using geophysical prospection (SSS, GPR, MBES) in both peatland and shallow water conditions [17]. In this project, the most typical factors challenging the detection of inundated sites remotely were well-attested, namely, insufficient physical contrast, burial depth, small size of the target feature, and complex sediments, which complicate the use of these techniques. Whilst a few positive findings were made, more invasive methods, such as coring and test pitting, were often needed in order to validate fragmentary and indistinct archaeological assets. Other analyses that were integrated in this project included pollen analysis for paleoenvironmental reconstruction as well as extensive walkover (or fieldwalking) survey and excavations.

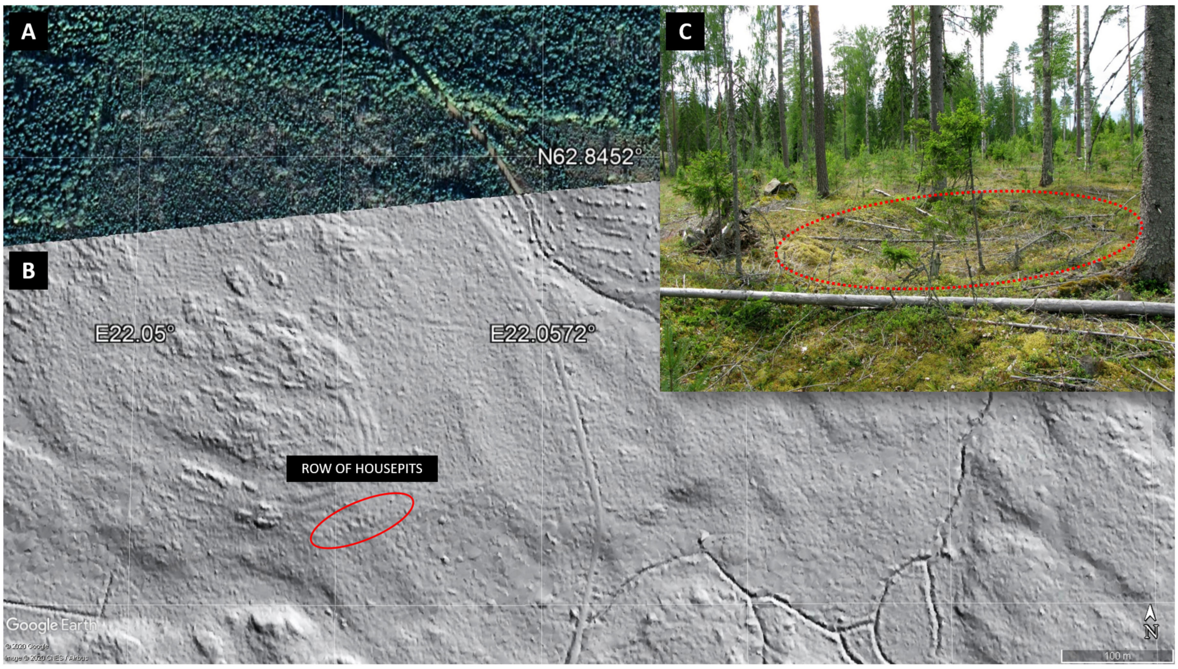

Figure 4. Stone Age housepit features are difficult to find and register via traditional fieldwalking survey in forested environments. They are often detectable in LiDAR generated digital terrain models (DTM) when they occur in clusters of several housepits. (**A**) An aerial photo of thick coniferous forest canopy at Laihia, W Finland; (**B**) 18 housepits and associated pit features in row formation in a LiDAR generated DTM at the Tuoressaari 1 site in Laihia. These features were validated via test pitting and surface find collection; (**C**) an individual housepit is difficult to discern on terrain. Background data provided by Google Earth and the National Land Survey of Finland. Illustration and photo by Satu Koivisto/SKAIK project, Finnish Heritage Agency.

Carmen Cuenca-García provided an overview of the development of the use of ground-based geophysical methods in Scottish archaeology with a talk entitled ***'Archaeo-geophysical survey in Scotland: going beyond the myth'***. She explained that for many years the 'myth' that "geophysics does not work in Scotland ... Scotland is too igneous for geophysics" was held amongst archaeologists and that the use of these methods was considered unnecessary as "geophysics does not provide any additional information than aerial photography". This odd perception or generalisation seems to have been triggered by a series of bad experiences using magnetometry in areas where other geophysical techniques should have been used. Cuenca-García described that the first movement to start changing this odd perception of archaeo-geophysics was made in 2003, when the contributions of geophysical surveys in Scottish archaeology were reviewed at the conference *Going over Old Ground* [18]. A second meeting to promote the potential of geophysical survey in Scottish field evaluation was organised in 2010 by the ALGAO: Scotland (Association of Local Government Archaeological Officers) and archaeo-geophysics interest group (GeoSIG) of the Chartered Institute for Archaeologists (CIfA) [19]. A period of review of the role of archaeological science in research and management in Scotland was initiated in 2012 within the Scottish Archaeological Research Framework (ScARF). This included an assessment and some guidance on the use of geophysical methods in cultural heritage management [20]. At a research level, there have been three PhD projects focused on exploring the potential of geophysical methods in Scottish sites [21–23] as well as a number of published studies that have showcased successful applications of different techniques [24,25] and integrated approaches [26–29].

Cuenca-García argues that these efforts have contributed to change the old perception that "geophysics does not work in Scotland". This change has been reflected in a growing number of surveys undertaken throughout Scotland especially for archaeological community projects. There has been a notable proliferation of companies providing archaeo-geophysical services, especially since developers can take their own initiatives and undertake their own geophysical exploration as part of planning applications. In most archaeological research projects, geophysical techniques are still used as a tool in preparation for excavations rather than to explore research questions. Additionally, training opportunities in archaeo-geophysics have diminished in the last years and only some introductory lectures are provided at some Scottish universities offering degrees in archaeology. She concluded that current trends include an increasing use of multi-channel systems for extensive surveys as well as a continuation of occasional studies where integrated approaches are used to explore subsurface sites and reconstruct paleo-landscapes, especially those that are located in challenging or remote areas [30,31].

The paper by Bates et al. [32] in the special issue showcases the later trend described above. They demonstrate that, by combining geophysical surveys and other remote sensing technologies, palaeo-landscapes can be reconstructed in challenging remote environments. In the paper, they reveal new information for palaeo-landscape reconstruction at the iconic archaeological sites on the isle of Lewis and also support previous speculation relating to the construction of a prehistoric monument on one particular location. Aside from shedding light on landscape development, the authors claim that these surveys "may also lead to novel insights into the perception of natural phenomena by past peoples that cannot be inferred by any other means".

Mikkel Fuglsang presented ***'Geophysical and archaeological developments in Denmark'***, an account of how Danish archaeologists have adopted ground-based geophysical techniques. Fuglsang reported that, whereas methods, like aerial photography and LiDAR, are frequently used in rescue archaeology as routine methods, ground-based geophysical methods have primarily been used as part of research projects to explore known key sites to showcase the potential of the techniques. He explained that the general appreciation seems to be that ground-based geophysical methods are expensive and yield very little information beyond what is already known by aerial photography or LiDAR. Furthermore, the majority of geophysical surveys have been carried out by foreign institutes or companies, so there is little local expertise. In 2014, his institution, the Midtjylland Museum acquired a multi-sensor magnetometer as part of a large survey contract for a new motorway north of the city of Herning. This project allowed for them not only to gain field experience in magnetometer surveying, but also to validate the results that were provided by this technique against the excavated features [33]. Fuglsang described that they routinely integrate this technique as part of the first phase of archaeological surveys to gain preliminary information which is used both to prioritise and interpret features in the field and improve budget allocation for archaeological excavations. Furthermore, new sites have been revealed by combining magnetometer surveying with metal detection and aerial photography. They are devoting efforts to explore other geophysical techniques and improve the understanding of how Danish subsoil characteristics and the type of archaeological features may affect the results provided by magnetometry to improve data interpretation. Fuglsang's opinion is that the perception of the use of geophysical techniques—at least, of magnetometer surveys—is changing and more Danish museums are opening their eyes to the potential of these methods.

The talk ***'Archaeological geophysics in Sweden'*** by Andreas Viberg provided an update of a review he published in 2011 [34]. He highlighted the appearance of different multi-channel systems since that time as a good addition to the list of suitable archaeological geophysical technologies in Sweden. He posed that geophysical surveys can and should be complemented by different geophysical techniques and geochemical methods, when appropriate, as different methods measure different soil physical properties and parameters. By using several different methods at the same site, it is often possible to obtain a more complete understanding of the buried archaeological remains [35]. In some cases, the geological and pedological characteristics of a site may hamper the results of some geophysical surveys (e.g., highly conductive soils and GPR). Therefore, the use of different geophysical techniques could then be the solution to an otherwise failed survey campaign. His opinion is that the future success and development of archaeological geophysics in Sweden hinges upon dealing with some challenges, including a general scepticism towards the usefulness of the geophysical prospection methods within the professional Swedish archaeological community, as well as an apparent lack of knowledge about different archaeological prospection methods among policy and decision makers. Viberg's opinion is that it is especially urgent to include archaeo-geophysical lectures as an integrated part of all introductory courses in archaeology to ensure that future professionals get a realistic view of both the pitfalls and possibilities of the methods. He stated that multi-channel and multi-method approaches to archaeological prospection offers a road to a more complete understanding of archaeological sites. However, there are important constraints in Sweden, as the funding opportunities for buying more updated geophysical equipment are quite limited. A possible way forward would be to look across country borders for joint solutions and collaborations. This would provide better tools and opportunities for handling the challenges of archaeological prospection in the North.

The paper by Viberg et al. [36] in the special issue demonstrates how high-resolution and extensive geophysical surveys can make an interpretation of large and complex archaeological sites feasible as well as to estimate the preservation state of buried archaeological features . The authors carried out a GPR survey using a multi-channel system to record the subsurface remains of a large Iron Age fort. The spatial distribution and geometries of approximately 50 prehistoric houses were identified with foundation preserved to different degrees, given the intensive farming. They also provide some recommendations to guide future rescue excavations required to ensure the full recording and safeguard of the site.

'Situating archaeological geophysics in Norwegian Cultural Heritage' by Arne Anderson Stamnes offered a perspective on the adoption and current role of ground-based geophysical methods in the national system of cultural heritage management, which was the topic of Stamnes' PhD research [37]. He analysed the content of various public management and policy documents (e.g., guidelines, action plans, scientific evaluations) to assess how geophysical survey methods were perceived within cultural heritage management in Norway. The potential of these methods for mapping, planning (e.g., help to prioritise and rationalise excavation areas) and development of prehistorical/historical knowledge was of interest in cultural heritage management. He described how the use of these methods in Norwegian archaeology has increased in the last two decades, although, as Stamnes explained, there is still a general lack of acceptance for including them as part of archaeological site evaluations. The main reason for this was a similar perception as that mentioned by Cuenca-García for Scotland—that the geophysical methods were not applicable in Norway due to the geological conditions, and the generally ephemeral nature of Norwegian Iron Age settlements in particular. Early surveys were not always well presented, with low and often unsuitable spatial resolution, and there has been a lack of general competence based in Norway. In addition, a tendency for over-interpreting early results left archaeologists with an impression that the methods "did not work". Recent advances in hardware and software in the last decade, especially involving large-scale high-resolution GPR surveys, have changed this perception. Stamnes described that there has been an increase in the geophysical surveys carried out since 2010, which fits initiatives that were taken by NIKU (in collaboration with the LBI ArchPro) and the NTNU University Museum. Since 2013, more surveys have been undertaken within cultural heritage management/planning purposes rather than for purely research reasons (Figure 5). Still, geophysical surveys are only included in less than 2% of all archaeological evaluations commissioned in Norway. Stamnes concluded that, whilst geophysical methods are no longer considered "new" and "untested" in Norwegian cultural heritage management, there is still need for further method development. He closed the talk with some other points on how archaeo-geophysical methods can be further developed. For example, the increased amount of both academic publications and reports could be used to provide new knowledge on the possibilities and limitations of these methods under the prevailing Norwegian geological/pedological conditions and type of archaeological sites. Additionally, it is important that this new knowledge is passed on to other research and cultural heritage actors through dissemination and training initiatives.

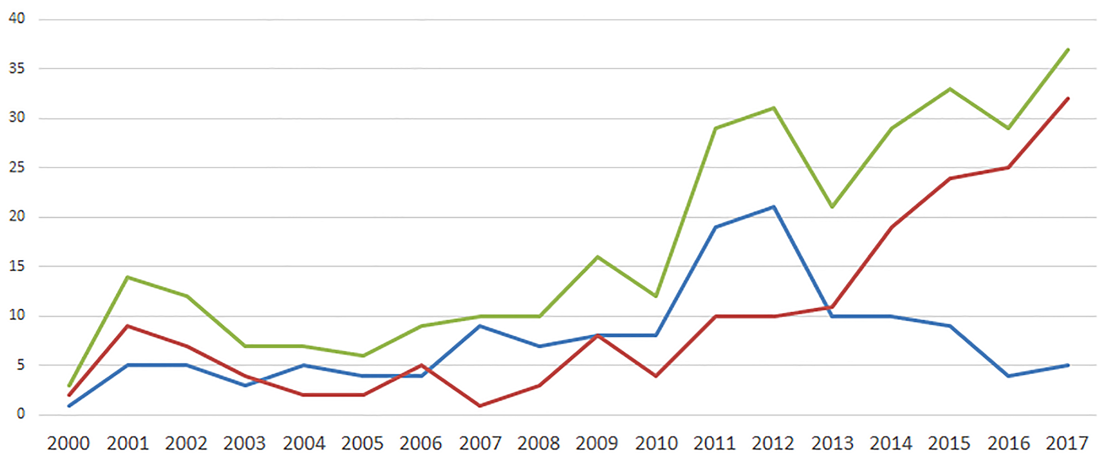

Figure 5. Research (in blue) versus management (in red) initiated archaeo-geophysical surveys in Norway. The total number of surveys is shown in green. Graphic by Arne Anderson Stamnes.

In addition to this presentation, a comparative study is published in the special issue, where Gustavsen et al. [38] quantified the detection rates and precision of the results that were provided by extensive GPR surveys data and trial trenching carried out at two sites. The goal of the study was to assess the advantages and disadvantages of these methods in archaeological site evaluation, a procedure used in cultural heritage management to assess whether there is a conflict between a planned development and any archaeological feature present at the site. They observed that organic and charcoal-rich features were easily detected by both methods and, whilst the overall spatial representability was similar, the total detection rates were lower with GPR than for trial trenching. The authors argue that rather than replacing one or the other method, full-coverage GPR surveys prior to test trenching seems to be a good strategy in archaeological evaluation to assess a site. Access to large scale, high resolution GPR data provides information that can help prioritise where to place evaluation trenches or do full scale excavation, and that can help to rationalise both the time used in the field and for budgeting and bureaucratic stages of the management of the planning permission.

Several case studies illustrating different applications of terrestrial and marine sensing methods in archaeological research and cultural heritage management were presented during the second day of the workshop.

Dag-Øyvind Solem's talk ***'Small-scale and large-scale digital documentation at NIKU—from RTI to drones'*** focused on his experiences with photogrammetry and reflectance transformation imaging (RTI) photography in different case studies. These include photogrammetry-based 3D models to document artefacts (https://skfb.ly/6TUzw), furniture (https://skfb.ly/6StAD), buildings (https://skfb.ly/6CEAD), and excavation sites (https://skfb.ly/66RTW), or combining photogrammetry and ground-based laser scanning, as in the cases of the St. Clement's excavation in Trondheim and Holtålen stave church (https://youtu.be/VQuJJqjKdEY). He noted that photogrammetry can be an expensive and time-consuming method and that the inclusion of laser scanning may improve the results in situations where the lighting conditions are not perfect. Further, the use of unmanned aerial vehicles (UAV) photogrammetry can facilitate the documentation of large areas, such as entire archaeological sites (https://skfb.ly/6BLpp), landscapes (https://skfb.ly/6CZpy), and buildings. He discussed his winter experiences of drone photography and the use of autonomous flight photography. Given that photogrammetry often struggles to capture surfaces with few details [39], the process was surprisingly successful when documenting snowy landscapes. Furthermore, the use of autonomous flight greatly improves the efficiency and quality of UAV photogrammetry, as the programs allow the UAV to quickly capture a great number of pictures with predetermined overlapping patterns, reducing the need for numerous flights that are caused by limited flight time. Solem also shared his experiences with RTI photography to capture small surfaces on objects and walls. RTI results in very detailed '2.5D-models', which consists of two-dimensional (2D) models that contain topographical information. These models can be manipulated using free software to accentuate details, and have been used to document coins, paint, graffiti inscriptions, etc. He described the results of a comparative analysis where he documented the same surfaces with photogrammetry, handheld laser scanning and RTI photography. This showed that the RTI photography produces the most detailed results, but the viability of the method is significantly restricted by a number of factors. The resulting 2.5D models lack the benefits of 3D models, for instance they may only be viewed from one angle and may not be georeferenced or used for measuring. He concluded by highlighting the benefits of combining photogrammetry and RTI as this provides all the benefits of 3D modelling as well as gaining very detailed textural information.

In Solem et al. [40], which was published in the workshop's special issue, the potential of RTI and photogrammetry (in specific, image-based modelling-IBM) is further explored and two new ways of combining RTI and IBM are introduced. While the methods have been combined previously [41–43], they have been used separately, for instance, by using RTI to record an inscription and using IBM to record the wall the inscription was inscribed on. The two new ways of combining RTI and IBM that are considered in the paper, are both based on image acquisition and model generation, overlapping images acquired while using the Rigged Light (RL)-RTI technique. IBM, RTI, and the two combination methods are assessed by the factors of usability, time-efficiency, cost-efficiency, and accuracy, in order to document miniature incisions (old graffiti) in two surfaces of two 13th century building stones from the Nidaros Cathedral (Trondheim, Norway). The authors found that there is currently not a single recording technique that is optimal regarding all four aforementioned factors of assessment, and the technique should be chosen based on their prioritisation. They argue, though, that the two new ways of combining IBM and RTI add valuable options, as one of them is cheap and fast and the other provides the most detailed three-dimensional (3D) models.

The presentation conducted by Manuel Gabler ***'Geophysical archaeological prospection on snow-covered areas with motorised ground-penetrating radar array systems'***, published in the special issue, reported their winter surveying experiences at four Norwegian archaeological sites [44]. The goals for their investigations were to develop practical solutions for motorised GPR surveys on snow as well as to evaluate to which extent the thickness of snow cover affects the data quality for archaeological purposes under real conditions. His account is based on the results obtained with NIKU's motorised multi-channel GPR system (using 400 MHz central frequency antennas), which has been frequently used on snowless conditions since 2010. It is based on Guideline Geos MIRA system and has been further adapted for archaeological purposes by the LBI ArchPro. For the snow measurements, their system was mechanically adapted by equipping snow crawler belts on the vehicle as well as changing the mounting and skid-plate of the GPR antenna box. Gabler compared these results against data that were previously obtained under snowless conditions that clearly identified subsurface archaeological remains. Beside the findings, he noted that the mechanical adjustment worked well at areas with up to 1m thick snow and enabled investigations nearly as fast on snow as on dry conditions. As an added advantage, the snow-covered landscape and frozen ground permitted access to areas that otherwise would be inaccessible for motorised GPR prospection. The data that were collected at the Borre site showed that a thin layer of snow over frozen ground resulted in the best-contrasted GPR data obtained at that site to date. At the Lågendalen and Stange sites, the archaeological remains were detected, even under thick snow cover, although with reduced imaging resolution. In contrast, the results at Sem were not satisfactory as the archaeological remains were not detected under 30 cm thick snow cover. Whilst no measurements of the snow quality and soil humidity were conducted at that time, the authors consider that the lack of detection here was due to higher temperatures, which resulted in different snow compositions. This could have limited the penetration of the GPR signal through the snow layer and respectively wet topsoil. In order to understand this effect better, the authors plan further measurements. He concluded by noting that large-area GPR surveys on snow-covered areas could provide a good opportunity to extend the fieldwork season, providing easier access to agricultural fields. However, optimal snow and ground conditions for GPR surveying needs to be better understood.

The first contribution about sensing methods in marine archaeology came from Øyvind Ødegård with the presentation ***'Underwater robotics in marine archaeology—towards autonomy'***. He described the recent advances in underwater technology, regarding both platforms and sensors, which could greatly benefit marine archaeology. Ødegård explained that advanced control systems enable the high precision manoeuvring of remotely operated vehicles on the seabed, even at great depths. Additionally, autonomous systems enable robots to perform sophisticated operations with limited human direct control or oversight [45]. Synthetic aperture sonar (SAS) mounted on an autonomous underwater vehicle (AUV) deploys advanced long-range sonar signal to achieve high-resolution imagery and 3D-data of large seabed areas. Ødegård highlighted SAS imaging as a technology with huge potential for autonomous mapping of underwater cultural heritage (UCH) [46]. He also called attention to underwater hyperspectral imaging (UHI) as a novel close-range optical technology, which is currently being tested on UCH sites [47]. This can classify and, hence, detect materials that are typically found on modern era wreck sites. Ødegård also talked about stereo cameras mounted on ROVs that have been used to build high-resolution photogrammetry models of several wreck sites, demonstrating capabilities for efficient, comprehensive, and detailed recording of seabed features.

As part of several interdisciplinary research cruises, both in the Trøndelag region and in the high Arctic, the NTNU Applied Underwater Robotics laboratory (AUR-Lab) applied the above-mentioned technologies to map and record marine archaeological assets. This is illustrated by the special issue contribution by Mogstad et al. [48], a paper that showcases the value of applying complementary sensing and optical methods to wreck site recording and assessment. The study focuses on the documentation of a wreck, discovered in 2007 in Trygghamna (Isfjorden, Svalbard). The authors describe how they identified the wreck as the Figaro, sunk in 1908, using an AUV equipped with SSS and a mini-remotely operated vehicle (ROV) with a high-definition (HD) camera during a visit in 2015. In January 2016, they carried out a photogrammetric survey with a ROV as well as UHI. The analysis of the resulting 3D model and classified UHI allowed for them to assess the levels of biofouling (accumulation of microorganisms, plants, algae, or small animals on wetted surfaces).

They found that archaeological objects sticking out of the seafloor support significantly higher levels of biofouling than their surroundings, and these dense biological assemblages could serve as proxies for identifying marine cultural artefacts.

'King Øystein's harbour—understanding a site through joint marine and terrestrial investigations' by Fredrik Skoglund focused on the possibilities that the application of advanced mapping methods and landscape analysis can offer to fully understand the exceptional King Øystein's harbour site (Agdenes, Norway). Skoglund explained that, although generally accepted as having been constructed during the reign of King Øystein (AD 1103–1123), there is nevertheless uncertainty regarding form, function, and origin despite almost 200 years of site investigations [49–52]. Additionally, it is one of the very few sites in Norway from the Middle Ages with constructions still in situ, above and below water, which makes it both interesting and challenging. Interesting in terms of mapping and environmental monitoring. Challenging with regards to conservation and site management as the site is located in the intertidal zone and exposed to a high level of seawater and weather erosion (Figure 6). During the presentation, Skoglund looked at the possibilities that advanced sensing methods and landscape analysis can offer to fully understand this site. He highlighted that the site is especially well-suited to test various methodological approaches, as it demands an integrated geophysical prospection and modelling of the coastal area surrounding the existing structures to reconstruct changes related to the harbour structures and shoreline configuration. Data are available from several previous investigations and, although their quality and usability vary, they have to a lesser degree been combined. Skoglund's intentions are to combine the historical documentation with various marine and terrestrial sensing and optical methods to eliminate the current distinction between land and water and achieve a holistic reconstruction of the harbour and its environs in the early medieval period.

Another contribution, which focussed on the study of a historic harbour site (Igaliku, Greenland), was submitted in the special issue by Wilken et al. [53]. They use SSS and a reflection seismic system in order to reconstruct the former coastline during the first centuries of the Norse settlement period (c. 11/12th centuries). They also aimed to detect archaeological remains on the seabed connected to maritime traffic and trade history. Whilst they did not reveal any archaeological remains with the SSS survey, they produced a high-resolution bathymetric map from seismic seabed reflection to achieve the coastline reconstruction. They realised that a small island, which hosts the ruins of a tentative Norse warehouse at the mouth of the present harbour, was connected to the shore at low tide during the early Norse period. In addition, reflection seismic and SSS images reveal a submerged topographic feature on one side of the island, which may have functioned as a landing "bridge". The coastline reconstruction also provided evidence to the debate about the fate of the Igaliku colony. The authors' modelling shows that the sea level rise for the period was insignificant when compared to the available fertile land in the fjord. Thus, they declare that there are no grounds to suggest an abandonment of the settlement, because of the loss of fertile land.

The workshop presentations concluded with the keynote by Richard Bates on ***'The Europe's Lost Frontiers project'***. He began by describing how, since the Last Glacial Maximum, a warming climate has caused global sea-level rise and the inundation of vast landscapes that had once been home to thousands of people. These areas, and in particular those on the European Continental Shelf, are being investigated by the project. Bates explained that this is a multidisciplinary research effort to uncover these lost lands that hold a unique and largely unexploited record of settlement and colonisation from a key period in prehistory, the Mesolithic, at the transition between hunter gathering societies and sedentary farming. He described the range of expertise (i.e., archaeo-geophysics, palaeoenvironmental analysis, including molecular biology for sedimentary ancient DNA analysis, and computer simulation) they are using to explore these past environments, the ecological change within them, and the implications that this has for human society. He highlighted Doggerland, in the North Sea basin between continental Europe and Britain, as a focus of the project. He explained that this is an area that would have been a heartland of human occupation and central to the process of re-settlement and colonisation of north Western Europe during the Mesolithic. Within this now-submerged landscape lies fragmentary yet valuable evidence for the lifestyles of its inhabitants, including the changes that result from both the encroaching sea and the introduction of new technologies from further east. While the project is working with broad-scale geophysical techniques such as seismic analysis it is also providing the necessary information to target investigations of areas with intense detail including the core analysis. Both of the elements, he noted, are vital to the success of the project, which will also produce a series of new computer-based models for testing theories of change.

Figure 6. North facing picture showing the location of part of the King Øystein's harbour's structure in the intertidal zone which poses challenges of protection and management. The log in the centre of the image is 1.25 m in length and it was originally a part of the base of one of the wooden caissons that constituted the breakwater. Photo: Fredrik Skoglund, NTNU University Museum.

4. Roundtable Discussion

Taking into account both academic and cultural heritage management perspectives, the discussions covered three aspects: current applications (day 1); challenges and future directions (day 2). This section provides a summary on some key pointst that were identified during the technology-based group discussions, which were shared later in a plenary roundtable session. The following participants composed these groups: aerial/remote sensing methods (Satu Koivisto, Esben Mauritsen, Ole Risbøl, and Dag-Øyvind Solem), ground-based geophysics (Carmen Cuenca-García, Mikkel Fuglsang, Manuel Gabler, Wesa Perttola, Arne Anderson Stamnes, and Andreas Viberg), and marine sensing methods (Richard Bates, Fredrik Skoglund, and Øyvind Ødegård).

4.1. Aerial/Remote Sensing Methods

4.1.1. Current Application

Aerial based remote sensing incorporates satellite imagery, aerial photos, LiDAR, and various instruments mounted to UAVs. These are the most common applications used for archaeological prospection from aloft. The employment of satellite imagery for archaeological purposes has been limited compared to that of airborne LiDAR in the Northern countries [54]. Archaeological communities engaged with LiDAR very soon and added it to their tool-box after the technique became an available possibility for archaeologists just after the turn of the millennium. Norway was the leading country in that respect, subsequently followed by a gradually introduction of LiDAR in the other Nordic countries. In the current workshop context, presentations and the roundtable discussion were almost solely about LiDAR and, to some degree, aerial photography and drones. Thus, only these will be addressed here. Aerial reconnaissance by means of oblique and vertical photos has been employed only sporadically for archaeological purposes in the Nordic countries, except for Denmark. In Denmark, aerial photography has a long tradition and some rather large-scale projects have been carried out in recent years [12,55]. These have generated very good results with the identification of a large number of hitherto unknown archaeological features and sites along with comprehensive new knowledge about land-use in the past. LiDAR has over the years received a lot of attention in the North—although at various pace as well as unequal weighting when it comes to research and development initiatives (see Risbøl et al. this volume). Development initiatives have followed two main avenues: studies that are focused on the efficiency of LiDAR in mapping archaeological features in forested environments [6,7]; and, the development of semi-automatic detection procedures [56,57]. Since its introduction approximately 15 years ago, LiDAR has been well received by the archaeological community, where it has gained a firm foothold within the field of cultural heritage management. The availability of data through national airborne laser scanning campaigns has strongly affected the use of LiDAR in archaeological research and cultural heritage management (see Risbøl et al. this volume). The use of UAVs (especially drones) has made good headway over the last years in Nordic archaeology with emphasis on landscape documentation as well as 3D photogrammetry.

4.1.2. Challenges and Way Forward

The use of LiDAR for increasing factual cultural-historical learning is very limited amongst archaeologists in the North. The potential for advancing our knowledge about how people in the past engaged with their surroundings is at hand, but remains, so far, an almost untapped possibility [58]. This is in contrast to many other regions across the world. Other unused possibilities when it comes to LiDAR data are studies focused on utilising intensity data (variations in the reflectivity of returned laser pulses), which is a secondary output of laser scanning data [59,60]. Additionally, bathymetric scanning remains to be tested for archaeological purposes in the North.

Two topics appear as the ones where we can expect substantial progress ahead that is related to the two fields of drones and public participation, respectively. A few initiatives have been made with regard to exploring the outcome of LiDAR from drone platforms [61]. This is an area where we are more or less at the starting line, but where LiDAR development inevitably will increase heavily. The same statement can be applied to the growing trend of public participation or community archaeology where LiDAR data are playing an increasingly important role [62–64].

Aerial remote sensing has been an opportunity in archaeology for decades and further development and progress can be expected. Developments are made continuously and will proceed in the future. Exchanging competence and experience as a part of trans-disciplinary and trans-national cooperation is a main success factor in research and development projects and a key to obtaining best possible achievements—also ahead.

4.2. Ground-Based Geophysical Methods

4.2.1. Current Application

The current application of ground-based geophysical techniques (inter alia, GPR, magnetometry, frequency domain electromagnetic induction, earth resistance mapping, or electrical resistivity tomography) as part of archaeological research projects in the North is quite generalised and shows good demand. In particular, large scale GPR and magnetometer surveys using multi-channel and vehicle-towed systems are quite common. This is because the optimal conditions provided by the frequent farmlands to explore (e.g., extensive and relatively flat/obstacle-free) with potential good contrast between the physical properties of the expected buried archaeological features and those of their surrounding soil environment. These types of surveys are frequent in Norway, Denmark, and Sweden to investigate, for example, Iron Age settlements and fortifications. These surveys are also starting to become more common to study Scottish archaeological sites at some regions, such as the Lowlands, to locate buried Roman fort structures or negative features (e.g., post holes, ditch-like enclosures) that are related to prehistoric sites.

Their integration in cultural heritage management has been more complex in several countries covered in this workshop with a longer tradition using these methods (i.e., Scotland, Sweden, Norway and Denmark). A commonly conveyed impression was that odd perceptions regarding the usability of these techniques grew between some archaeological professionals. The reasons behind this included early bad experiences using techniques at non-suitable sites, and the weight of aerial photography tradition in archaeology in some countries. Odd perceptions included considering geophysical surveying as a replacement of traditional test trenching, instead of a complement. Low-resolution and over-interpreted data as well as a lack of trained personnel has also played a role. This is illustrated in the presentations by Cuenca-García, Viberg, Stamnes, and Fuglsang for the overviews on Scotland, Sweden, Norway, and Denmark, respectively.

Nowadays, it seems that the role of geophysical surveying in archaeological site evaluation is more understood and its use as part of the planning process and mitigation strategies is increasing. This is the case for Scotland, Norway, and a trend in Sweden and Denmark. In the case of Finland, these techniques are also slowly starting to be introduced, but more basic/baseline research and testing is needed. A geophysical survey seems to be considered valuable in site evaluation and mitigation, especially as part of medium to large-size new developments or infrastructures (e.g., roadworks and railroads). Since 1994, the use of geophysical survey techniques in site evaluation has been suggested in paragraph 20 of the Scottish Planning Advice Note [65]. In April 2020, a white paper on cultural heritage policy published by the Norwegian government dedicated a section on the use of geophysical methods [66]. The section highlights the potential of geophysical survey methods to contribute to new archaeological knowledge and cultural heritage management, the existence of national competence and infrastructure, as well as the need to find solutions to facilitate the commission of these methods by different stakeholders (i.e., county archaeologists, municipalities, the Sami government, and developers).

4.2.2. Challenges

Continuing with the assessment of ground-based geophysics in cultural heritage management, the challenge now is to avoid the proliferation of inappropriate surveys. There is still a need to keep developing good-practice and communicate this to non-expert commissioners and/or occasional users. Communication should explain the potential but also the limits of these survey methods, showcasing good results, but also detailing where these do not work. Archaeological officers commissioning geophysical surveys and assessing the consequent reports should all have a general understanding about the capacities of the range of geophysical techniques that are available and what to expect in a report. In this regard, standardisation of reporting is fundamental. The general agreement here was that the guidelines in reporting produced by the European Archaeological Council (EAC) should be adopted [67]. This followed with a discussion on whether there was a need to develop more comprehensive national guidelines to provide an overview of the aspects to ponder commissioning, planning, or implementing geophysical surveys in archaeology. The general agreement was that the EAC guidelines could also apply under the current technology state. These guidelines include a part that introduces the different geophysical techniques and respective field methods.

A key aspect of the adoption of geophysical methods in archaeology has been understanding the suitability of particular sites and their environmental contexts for the different techniques. Scandinavian and North Atlantic survey environments, which are characterised, inter alia, by the effects of glacially-shaped geologies/superficial deposits/landforms, presence of snow-cover, organic and waterlogged soils (peat), permafrost, and its variable thawing layer, can be challenging for some of these techniques.

Whilst some techniques have shown a prevalence for use in specific countries (e.g., GPR in Norway), this should be taken cautiously. The commissioning of a geophysical survey and decision on the technique/s to use should be based on a careful assessment of the environment to be explored and, if known, the characteristics of the expected archaeology. Decision-making should not be based on the employment of a 'default' or 'popular' technique. As experience shows, the lack of knowledge of which are the optimal/non-optimal environmental conditions of a survey area risks commissioning inappropriate surveys.

Additionally, the best strategy has always proved to be the employment of complementary techniques instead of relaying on a single one. It has been argued that this increases the cost of surveys. The limitation in instrumentation availability, given the lack of funds to invest in infrastructure that countries have/may face, could make the implementation of integrated geophysical surveys difficult. These financial constraints could be overcome in the future and encourage more multi-technique geophysical surveys while taking into account the possibilities for instrument sharing as part of institutional collaborations or wider national/international strategies.

In order to assess the optimal set of techniques, apart from particular experience and knowledge, the use of databases providing information about soil, geology, and other data about the survey environment to explore, can be useful. As result of this discussion, this group put together a searchable datasheet listing some key online resources that may be of help during the planning or interpretation phase of archaeo-geophysical studies (detailed in the Supplementary Materials) [68]. Additionally, in order to facilitate access to previous surveys, searchable archaeo-geophysical databases are needed, such as those that started in Scotland (now mostly integrated in the Historic Environment Scotland's database 'Canmore') and Norway [69]. These dedicated databases should include the reports derived from each entry or, if the entries are included in the general national cultural heritage database (like in Scotland), to facilitate the upload of the geophysical reports.

Another discussion point was the general appreciation existing amongst archaeologists of geophysical characterisation as a bare mapping tool in preparation for excavations (i.e., the presence or absence of subsurface archaeology). Beyond site discovery, now quite achievable given the large areas multi-channel systems can explore, several studies have demonstrated that integrated surveys can provide useful information regarding paleoenvironmental aspects and ancient human occupation [70–72]. Especially if combined with soil characterisation, geophysical techniques can provide insights about stratigraphy and taphonomic/soil-related processes that are related to the genesis of geophysical contrasts and detection of archaeological features [30,73,74]. This extra level of information should be exploited more to derive information about the state of preservation of buried archaeological assets. Further, integrated geophysical and other soil analyses that are typically applied in prospection can provide a better understanding of how the environmental setting of a site may affect both geophysical and geochemical results and distinguishing between natural and anthropogenic anomalies [75].

Some final points to highlight from the discussion include the debate about the general reduction (and high demand) on training opportunities for knowledge on geophysical methods. Additionally, the necessity to invest in national expertise and training efforts in order to: guarantee a stable research environment; achieve a general understanding of the potential and limits of these techniques between all stakeholders involved in the management; and, ensure a 'healthy' adoption in archaeological management. Finally, the group discussed the need to develop more efficient approaches to interpret the large datasets that are produced by large-scale surveys using multi-channel systems.

4.2.3. Way Forward

Based on the needs that are mentioned above, future actions should include the development of training opportunities for students to ensure the new generation of archaeologists start their professional careers fully aware of the capacities of ground-based geophysical techniques. Training should also focus on showcasing good practice in these techniques, targeting national heritage boards, policy makers, museums (in the Norwegian, Swedish, and Danish cases), regional archaeologists, as well as other stakeholders involved in the planning process, such as construction companies and road authorities. A close communication with these stakeholders on the current uses and developments of these methods is required in order to avoid any emergence of odd perceptions or misunderstandings in what the role of ground-based geophysical methods may be in cultural heritage management. Taking care of this aspect is particularly important in those countries in the process of adopting these methods (e.g., Finland). Further, conveying feedback from previously surveyed excavations is an action that should keep happening between archaeologists and archaeo-geophysicists. This will facilitate technique reappraisal and the improvement of field methods and strategies.

Of course, we need to encourage projects which target archaeological research questions. However, it is also very important to inspire new approaches: we need to support the development of studies that are based on technique reappraisal, testing, and development in order to continue improving field methods and survey strategies. Funding the latter may be difficult given the scope adopted by many EU sources and the relative unsuitability of their funding criteria. Current funding opportunities provided by the ongoing *COST Action SAGA* (www.saga-cost.eu/stsm.php) and others, such as the membership association *ISAP* (www.archprospection.org/isap-fund) may be a temporary/small-scale solution to support such studies. In the past, testing/experimental projects have been funded as part of occasional PhD projects. The *DART* project (Detection of Archaeological residues using the Remote Sensing Techniques) aimed at identifying the optimal conditions and techniques (airborne and ground-based sensing techniques) to detect archaeological assets [76]. This was a large-scale monitoring project, involving several PhDs and it was funded at a national level. The *Borre* project [77], also investigating the optimal conditions to detect archaeological remains (with GPR), has recently been funded at a sub-national level. It is apparent that sources of funding for experimental/technique-development projects are sporadic, at best. Beyond this discussion forum, the overall community in archaeo-geophysics, including the COST Action SAGA network, has recognised the importance of and need for these types of projects. Therefore, the scarcity of such projects may not be due to a lack of interest within the research community, but more related to the issue that researchers do not find a good fit in the larger research schemes. This may be because funding bodies do not yet recognise the importance of technique development in archaeo-geophysics and do not cater for it in their funding criteria. A critical need to promote the funding for technique development in archaeological geophysics in the North is to develop strategies to market this type of research, so that funding can be sought directly, instead of being forced to piggy-back on more traditional archaeological research projects.

Further efforts should focus on facilitating instrument accessibility/sharing to center financial efforts in developing and stabilising human capacity and encourage research development. In this regard, the SAN network has recently put together a searchable and evolving datasheet collecting available equipment in public institutions [78]. This will integrate instrumentation concerning all SAN-related technologies.

4.3. Marine Sensing Methods

4.3.1. Current Application

The group discussed the issues of landscape scale investigations versus those at a site scale. The debate particularly focused on the dominant position that wreck sites have played in the past with regard to maritime archaeology and marine sensing. This has deviated the development away from the recognition of structures (e.g., habitation) or landscape mapping. Recent advances in an array of geophysical technologies for both seafloor mapping (i.e.mapping objects that are upstanding on the seafloor) and mapping features that are buried by sediment have led to the far greater use of geophysics for archaeological investigations. The advances have included an increased resolution in the technologies and a cost reduction in their use with the widespread adoption of remotely operated vehicles and, most recently, autonomous underwater vehicles. It was noted that the use of geophysics in marine archaeology did not need to convince sceptics in a similar manner to ground-based archaeo-geophysics. The marine use of remote sensing and geophysics is matured to a level where the relevance and justification is not challenged for wreck-type projects. However, other uses in marine archaeology are limited, as explained below.

4.3.2. Challenges and Way Forward

Data acquisition that is related to marine sensing methods happens over large areas, increasingly with higher resolution relevant for archaeology. However, archaeologists often only get involved at the end of a mapping project. Rarely are the wide area projects undertaken with archaeology as the main reason or with archaeologists brought in at an early stage. Most of the new projects are development-led for the wet renewable industry and engineering works.

In marine archaeology, surveys that are designed to map submerged prehistoric landscapes with remote sensing methods will not likely stop or otherwise obstruct, for example, an infrastructure project (e.g., marine wind farms). Therefore, any data derived from such development projects, would only be seen by an archaeologist as an opportunity to gather data, where it would otherwise not be possible to get any, thus it would add value for cultural heritage. The common reluctance to collaborate with marine archaeology is based on the fear of discovering a wreck site that stops a development project. This situation is best overcome by building trust and understanding between marine archaeologists and developers to emphasise the potential common benefit of new knowledge in this field within such developments. It is recommended that more effort is made to find collaborative routines to ensure that archaeology does not necessarily delay projects or add unreasonable costs.

There is a need for more routine data collection at an appropriate scale and resolution for making wide area maps. Collaboration on a national level between government agencies investing in and depending on mapping (e.g., the navy, coastal administration, and mapping authority) and archaeological bodies is needed [79]. A cost reduction for 3D sub-bottom profiling sonars (SBP), like 3D Chirp, remains necessary in order to map beneath the seafloor for buried archaeology as well as to improve the resolution and definition of underwater magnetometry to match that which has been achieved on land over the last 20 years. Other technology needs include the development of optical sensors (like LiDAR) to filter near field «noise» produce by kelp, make better defined models of upstanding objects on the seafloor, and integrate these with multi-spectral data to better characterise biological growth on artifacts. Recent developments in autonomous underwater technologies enable longer duration interdisciplinary surveys deploying multiple sensors, performed without humans in the loop. Together with other relevant marine sciences, archaeology needs to engage scientifically with these new "intelligent" capabilities to ensure high relevance and quality in data acquisition [80].

Sampling strategies (coring) for obtaining ground truth data for landscape appraisal of marine geophysical surveys could be better adapted to archaeological requirements/needs. This could be the case if the archaeologists were involved at earlier stages in a project, rather than the archaeology being viewed just as an exercise to meet regulatory requirements (ticking the boxes). The visualisation of geophysical data not only for science, but also for public dissemination, is important. Higher resolution presents new opportunities for such outreach. However, the onus is on the archaeologists to do something in this area. Visualisation through photogrammetry models is further important to better portray the underwater cultural heritage to the public and decision makers, which is applicable to an array of sites with data acquisition from divers and remote sensing vehicles.

Collaboration is the key to marine based archaeology as the costs as compared to land is often of an order of magnitude greater. Joint research projects are proposed between academic collaborators and industry on broad areas (e.g., North Sea; HUGIN AUV with SBP Chirp) and with very high resolution projects, in particular those that integrate land and sea in a contiguous landscapes, as suggested by Skoglund in his presentation about King Øystein's harbour.

With increased awareness of climate change and other pressures on marine environments, attention towards ocean science, in general, is growing. The UN Decade of Ocean Science for Sustainable Development (2021–2030) initiative [81] is rapidly gaining support on multiple levels, calling for stakeholders to come together for the common cause of keeping our oceans healthy and productive. Integration of cultural heritage perspectives into this initiative is important for many reasons [82], not least when considering the focus on cross-sectoral collaboration, technology transfer, and sharing of data and information. The relevance of technological expertise and capacity existing in various marine archaeology communities should be highlighted and promoted, both regarding industry and the wider marine sciences.

5. Conclusions

The workshop *Sensing Archaeology in the North* was an occasion to critically discuss the development and current status of the use of non-destructive geophysical and remote sensing methods for studying archaeology in Denmark, Finland, Norway, Scotland, and Sweden. The participants identified some key needs and defined future directions for development, which are described in Section 4 (Roundtable Discussion) in this paper. Attendees were able to get to know/receive feedback about past and current projects. The activity encouraged the organisation of the special issue, opening the opportunity to publish some of the workshop presentations more extensively as well as embrace other contributions from other interested researchers and extend geographical coverage (i.e., Greenland).

Whilst the use of geophysical and remote sensing methods as part of archaeological research projects is generally in good demand, their adoption and current use in cultural heritage management varies between the different technologies and countries. It seems that management rapidly embaced marine and aerial/remote sensing methods, despite these methods also presenting some limitations and challenges.

The adoption of ground-based geophysical methods in cultural heritage management has been more challenging in some countries. The lack of consistent positive results, triggered by the inappropriate commissioning of surveys, mostly biased by the popularity of a specific technique, has led to widespread scepticism towards the usefulness and reliability of the methods. This pattern has been experienced in Scotland, Sweden, Norway, Denmark, and Finland (even though in Finland there have not been as many applied or experimental studies as in the other countries). Therefore, we propose some recommendations on the use of these methods in the evaluation of sites to be examined as part of the planning process/developments. Firstly, these methods should be always considered as an important complement to more invasive strategies. For example, the geophysical exploration of the development area prior to locating evaluation trenches can minimise the loss of the archaeological record, maximise diagnostics for site evaluation, lower the time needed for planning, and reduce the overall excavation costs. Secondly, the recommendation and selection of a specific technique/s, from all of the available range (inter alia, magnetometry, resistivity, frequency-domain electromagnetic induction, GPR, etc. . .) should always be done, in the first instance, according to the particular characteristics of the survey environment and expected archaeology. Finally, the development of training activities is needed in order to demonstrate the relative strengths and weaknesses of these methods to curators, regional archaeologists, museums, and developers to provide them with basic knowledge to assist them in the commissioning and evaluation of survey plans. Similar introductory training should also be adopted in all universities with degrees in archaeology and cultural heritage studies.

Overall, we position geophysical and remote sensing methods as playing a fundamental role in the discovery, recording, characterisation, and monitoring of archaeological sites and paleo-landscapes in the North. Taking into account the challenges that are posed by some survey environments in the North and types of archaeological targets, the way forward points towards complementary multi-method sensing investigations. Integrated approaches seem to be the best in order to secure success in detection, maximise the type of information extracted, and provide confident interpretations from non-destructively sensed data.

We claim the support of national and international funding bodies to back research efforts that are based on experimental/technique development projects to: explore unknown survey environments and identify optimal survey conditions (to inspire new approaches and advance in field methods and strategies); and, monitoring studies to ensure the safeguard and preservation of archaeological remains, especially those at risk. When considering the critical societal challenges that we face in safeguarding our cultural heritage for future generations, especially in the times of climate change, there is an urgent need to take full advantage of the possibilities available from sensing technology.

The *Sensing Archaeology in the North* workshop was an inspiring activity which resulted in the creation of the SAN network (www.san.network). We envisage a future workshop to strengthen and expand our current network, hopefully including other colleagues from the Faroe Islands and Iceland. We are confident that such network activities will aid in promoting future collaborations. We are also convinced that such activities could contribute to the development of solutions to reach local communities and wider society to engage them in caring for their cultural heritage and, on the way, to gain insights into cutting edge technology and science.

Supplementary Materials: The produced and evolving databases (online resources and equipment) are available at the *SAN* network website (www.san.network/resources). These databases are cited in the text as [68,78].

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