The Application of Geophysical Survey in Archaeological Research in Belgium: Current State and Future Perspectives

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Abstract Since its earliest applications in the 1970s, geophysical survey has been applied increasingly in Belgian archaeology. This was particularly the case within Flanders over the past decade. Academic archaeological research has played a fundamental role in disseminating available techniques, such as electrical resistance and magnetometer survey, and in advancing the use of electromagnetic induction- and ground penetrating radar instruments for archaeological prospection specifically. However, the dissemination of this expertise remains in its infancy and adoption in Brussels and Wallonia lingers behind. Although Flanders has seen a strong increase in such surveys over the past decade, the share that geophysical techniques take up in development-led archaeology pales to significantly wider used invasive prospection methods. Both a lack of tradition in archaeological geophysics as well as the dominance of systematic trial trenching as a prospection method underlie this slow uptake of geophysical approaches in development-led archaeology. In contrast, geophysical survey does play a significant role in academic (landscape) archaeological research and in the investigation of archaeological sites for scheduling. Within this general situation, the use of geophysical methods in Belgium is geared primarily towards specific expected types of sites, but, within the heterogeneous geological landscape, spans a wide range of environments.

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C. Cuenca-Garcia et al. (eds.), *World Archaeo-Geophysics*, One World Archaeology, https://doi.org/10.1007/978-3-031-57900-4_2

While progress has been made continually over the past decade, much room remains for further optimisation of the use of geophysical methods in Belgian archaeology. Here, improving protocols for the integration of complementary, invasive and non-invasive, survey methods adapted to the diverse geological and archaeological circumstances remains a key challenge. To enable these advances, current efforts to provide such a methodological framework, along with existing expertise across the nation, have to be disseminated beyond academic circles through initiatives, such as dedicated (post-)academic training and inclusion of both archaeologists and archaeological geophysicists. Hereby, the consolidation of a robust legislative framework, adhering to EAC guidelines, is required for implementing geophysics in (development-led) archaeology sustainably, similar to e.g. trial trenching. This should safeguard the quality, archiving, accessibility, and interoperability of resultant data.

1 Introduction

It is perhaps by virtue of its small surface area (30,528 km^2) that the Belgian territory has been subject of a vast range of high-resolution survey campaigns for a broad array of ecosystem services (Hassan et al., 2005). While regionalisation of Flanders, Brussels and Wallonia has stalled initiatives at a national scale from the 1970s onwards, the nation has a long-standing tradition of environmental mapping and surveying. Clearest examples are not only the early development of the 1:20.000 soil map (late 1940s–1970s) (Van Ranst & Sys, 2000) and 1:25.000 geological maps (1947–1977) (Boulvain, 1993) but also the extensive coverage of diachronic airborne vertical photographs from World War I onwards (Stichelbaut, 2006) and the public distribution of LiDAR data and derived products covering the entirety of Flanders (De Man et al., 2005; Meylemans & Petermans, 2017).

This survey density is part of a long tradition, building on historical cartographic endeavours from the sixteenth century onwards, e.g. by Pourbus (Trachet, 2018) and Ferraris (Vervust, 2016), as well as early geological mapping, e.g. by de Limbourg (Demoulin, 2018). After early attempts from the 1970s onwards, systematic inventorying of archaeological observations in Flanders has been ongoing since 2001 (Meylemans, 2004). This online *Central Archaeological Inventory*[1] (CAI) is partly public and fully open to registered users (ca. 50,000 records).

Such rich base maps are complemented by a particular richness of dedicated archaeological survey methods: starting from desktop research that hinges on the cartographic resource, complemented with invasive sampling approaches including borehole surveying and trial trenching, ideally combined in a case-specific manner.

This study aims to provide an overview of the current status of archaeological geophysics in archaeological research and archaeological heritage management in

[1] https://inventaris.onroerenderfgoed.be/waarnemingsobjecten/zoeken

Belgium. Over the past 15 years, geophysical survey methods have taken position between desktop and invasive approaches in a small share of the development-led projects (Meylemans & De Smedt, 2019). This prospection flow succinctly summarises the general approach to development-led archaeology, driven by the Valletta convention (Council of Europe, 1992). While not the sole motivator for conducting archaeological terrain exploration—archaeological surveys on sites not under threat do still take place for a variety of reasons—, development-led archaeology dominates the creation of new archaeological data.

2 Methodology

Aside from a review of legislation, an inventory of survey sites was made based on the CAI, the Flemish desk-based-assessment platform,[2] and an extended (grey) literature review. For each of the 311 inventoried survey projects, the employed technique, survey- or publication year, and survey objective were listed. For 306 projects, this inventory includes survey locations as points. The precise extents of all surveys as well as their specific method was not inventoried yet. Nevertheless, basic spatial analyses with other cartographic resources: the CORINE land cover (Büttner et al., 2004), the EGDI Surface Geological Map of Europe,[3] and the Belgian soil maps (Van Ranst & Sys, 2000) let us address the impact of the Belgian landscape and the nature of its archaeological features on geophysical investigations, both in academic research and in cultural resource management. We illustrate this by referring to selected key examples.

3 A Brief History of Archaeological Prospection in Belgium

Archaeological prospection is understood as the application of geophysical prospection methods in archaeology (e.g. Scollar et al., 1990) or as to the identification of areas of archaeological potential and individual strong anomalies using geophysical methods (Level I field strategy in Gaffney & Gater, 2003) in many countries and research traditions. However, in Belgium, the act of archaeological prospection includes the entire range of methods and techniques employed to detect, delineate, evaluate, and characterise archaeological sites and landscapes both invasively and non-invasively (e.g. S.n., 2019).

[2] https://loket.onroerenderfgoed.be/archeologie/notas/

[3] https://www.europe-geology.eu/

3.1 Aerial Photography

The current archaeological use of historical, vertical aerial photographs in Belgium originated in the late 1950s (e.g. Mertens, 1957) and has since then been applied with particular efficiency along the former World War I frontline (Stichelbaut, 2011). Along the use of legacy data starting around the same time, thousands of oblique aerial photographs were collected for archaeological purposes at the Centre Interdisciplinaire de Recherche Aérienne (CIRA) (Léva & Hus, 1975), followed by the universities of Ghent and Leuven (Meganck et al., 2004). However, systematic funding has waned recently and despite limited inventorying and thematic analyses, e.g. enclosure sites (Bourgeois & Nenquin, 1996) and Bronze Age barrows (De Reu et al., 2010), these collections remain understudied. The estimated workhours to catch up and disclose all available oblique aerial photographs surpass a decade. As a consequence, the usage of this resource in development-led archaeology remains limited to specific cases and inventoried subjects, e.g. World War I frontlines. However, as crop- and soilmarks are due to (often moisture-induced) soil contrasts, aerial photographs are not only essential to plan geophysical surveys, but they are also invaluable to interpret the resulting geophysical data (e.g. De Clercq et al., 2012b).

3.2 Walkover Survey

From the late 1970s to the early 2000s, walkover survey was employed to systematically inventory archaeological remains of dozens of municipalities (Nenquin et al., 1990; Van Daele & Tency, 2004). It was also applied in rescue archaeology and, in some regions, remains a widespread practice by amateur archaeologists (e.g. De Bock & De Meireleir, 2005). The results form a well-appreciated resource for academic researchers but have to be evaluated critically (Crombe et al., 2009; Trachet et al., 2017a).

Although inventoried results of past studies are used frequently in development-led desk-based assessments, the use of walkover survey has faded strongly and is barely practised in current archaeological studies in either development-led, heritage management or even academic frameworks.

Due to GNSS technology, allowing for artefact accurate walkover survey (AAS), this method has seen a limited revival in academic research. However, the full potential of AAS only reveals itself when combined with other methods, such as geophysics or aerial photography, to which it acts as a highly complementary method for assessing chronological and spatial parameters. When fully integrated with geophysics, UAV and LiDAR imagery as well as historical evidence, AAS has proven to be a useful tool to assess the archaeological record, e.g. of the medieval period, in a non-invasive way (De Clercq et al., 2018; Trachet et al., 2017a).

3.3 Trial Trenching

Whereas targeted test pits on known sites had already been used for a long time, developments abroad of systematic trial trenching as a survey method were introduced only gradually throughout the 1990s (De Clercq et al., 2012a; Meylemans et al., 2021). In the late 1990s, systematic 'Lorraine' (discontinuous) trial trenching was introduced for development-led prospection of large, rural areas (Blouet, 1994). More widespread adoption started only after 2004, due to changing legislation. Trenching patterns quickly evolved towards efficient continuous, parallel, 2 m wide trenches achieving an approximate area coverage of 10%. These are complemented by trench extensions ('observation-windows') with an area coverage of about 2.5% to resolve remaining uncertainties from systematic trenching. This has become rigid prospection methodology, easily applied in a commercial setting and embedded in the legal framework in Flanders.

While simulation approaches on a representative sample of archaeological sites without chronological differentiation generally confirm these approaches (Haneca et al., 2017), caution is advised due to a poor detection potential for low feature density rural sites and associated periods (De Clercq et al., 2011). Furthermore, this rigidisation of trial trenching methodology dissuades prospection at differing spatial scales, which is required to transcend the individual site (or project) level and to study intersite interactions as well as interactions with and within the archaeological landscape (De Clercq et al., 2011).

However, even if the legal framework prescribes the systematic trenching strategy, it allows for deviations (S.n., 2019). Nevertheless, through commercial market mechanisms, most warnings have been ignored in favour of a more easily implemented rigid system and currently little variability and innovation is observed in trenching strategies.

Due to this hard focus on systematic trial trenching for development-led archaeological prospection in Flanders, little room remains for integrating geophysical methods and trenching targeted on geophysical survey results, with few exceptions (e.g. Saey et al., 2016b).

3.4 Palaeolandscape and Archaeological Borehole Survey

In collaboration with geoscientists, who had been employing borehole surveys regularly since the interbellum, Belgian archaeologists started using this method to map buried palaeolandscapes for, primarily prehistoric, site contextualisation in the early 2000s (Bats, 2001). While the use for surveying soil features was abandoned relatively soon, manual borehole sampling was integrated into archaeological prospection as a means to detect Stone Age lithic artefact scatters in Flanders (e.g. Bats, 2007; Van Gils & De Bie, 2002), following developments in the Netherlands (Groenewoudt, 1994). As such, various research projects, often in a development-led archaeological framework, established strategies using Dutch (Edelmann) auger sampling to prospect selected positions within the reconstructed palaeolandscapes. More recently, sampling and sample processing parameters were evaluated using statistical (Verhagen et al., 2011, 2013) and empirical analyses (Crombé & Verhegge, 2015; Noens et al., 2013) and soon became standardised in regulations and development-led archaeology in Flanders (De Clercq et al., 2011), despite inherent imperfections addressed by e.g. Noens and Van Baelen (2014). Hereby, borehole survey for palaeolandscape reconstruction is considered a non-invasive method, whereas borehole survey for prospection of artefact scatters an invasive method from a legal standpoint.

Large scale and deeply impacting infrastructure works also led to the usage of mechanical coring, both for palaeolandscape mapping and archaeological sampling (Hissel & Van Londen, 2004; Verhegge et al., 2016b). To overcome the high cost of mechanical core sampling, additional methods for palaeolandscape mapping with higher spatial resolution, such as direct push sensing, primarily cone penetration testing, and geophysical methods, mainly electromagnetic induction survey, were investigated and introduced into development-led archaeology (Verhegge et al., 2016a).

3.5 Metal Detection

Although metal detecting is essentially a geophysical survey method for archaeological artefact detection, it is treated as a stand-alone discipline and a thorough discussion of its applications in Belgian archaeology is beyond the scope of this overview. Although illegal, non-professional practice was tolerated in Flanders until 2016 and in Wallonia until 2018 (Deckers, 2019). Since these dates, a legal basis was realised and regulations have become more stringent in Flanders and Wallonia. Hereby, metal detectorists are required to carry a permit, follow a code of good practice and report their activities and finds to the government. No specific legislation addresses metal detection in Brussels, although excavating artefacts without permit remains illegal (Jansen et al., 2020).

However, even if many permits have been issued, find reporting remains limited in Flanders (De Groote & Ribbens, 2021). This illustrates the distrust and disconnection from the archaeological community, despite efforts such as a citizen science platform[4] (Deckers, 2019). However, metal detectorists are frequently invited to work under supervision of professional archaeologists both in academic and development-led archaeological projects. A possible remediation through relating the metal detection community and (community) archaeological geophysics has not been explored yet.

[4] MEDEA: https://vondsten.be/

3.6 Geophysical Survey Methods

3.6.1 Common Evolution Before the Implementation of the Valletta Convention

Although integrating geophysical methods into standard Belgian archaeological workflows remains challenging, efforts had already been made to incorporate these into the standard non-invasive archaeological prospection toolkit roughly 50 years ago. Such efforts were mainly driven by investments in archaeological aerial photography by a select group of researchers in the 1950s and 1960s, paving the way for other, less conventional, non-invasive survey approaches. At the forefront of this pioneering work was the (private and independent) Centre Interdisciplinaire de Recherche Aérienne (CIRA; Interdisciplinary Centre for Aerial Research) established by Charles Léva, who recognised the potential of combining aerial photography with geophysical prospection from the onset. Exemplified by concerted actions such as the 1979 and 1986 conferences on 'Aerial Photography and Geophysical Prospection in Archaeology' (Léva, 1982, 1990), it was singly the seminal but offtime work of Jozef Hus in collaboration with Léva (Hus, 1982; Léva & Hus, 1975, 1984, 1987) that constituted the application of geophysical survey methods in Belgian archaeology for nearly three decades. Despite this early work and evolutions abroad, archaeological interest in geophysical methods waned throughout the 1990s (Fig. 1a), coinciding with the delayed standardisation of other survey methods and the slow development of a development-led archaeology. While unreported, the delayed spread of geophysical survey in archaeology could also be related to results being perceived as disappointing due to the complex subsurface environments of Belgium in combination with the ephemeral geophysical nature characterising a large portion of its (particularly rural and pre- and protohistoric) archaeology. Regardless of the reason, it is striking that across regions—in both academic and development-led frameworks—there was little to no uptake of geophysical approaches in Belgian archaeology during this period.

With the new millennium came a renewed academic interest into novel, landscape-oriented and non-invasive prospection approaches. Here, geophysical methods drew particular interest, which translated into several (academic and application-oriented) research projects that relied primarily on expertise from abroad (e.g. Masters & Stichelbaut, 2009; Quick et al., 2005; Strutt & Hay, 2003; Van Impe & Strutt, 2006).

3.6.2 Separate Ways After the Implementation of the Valletta Convention

Until the early 2000s, Flanders and Wallonia had been following a similar trajectory in the implementation of geophysical methods in archaeology. Despite some early applications by Léva and Hus (1975), the collaboration with experts (Quick et al., 2005) and early local expertise development (e.g. Charlier et al., 2001), geophysical

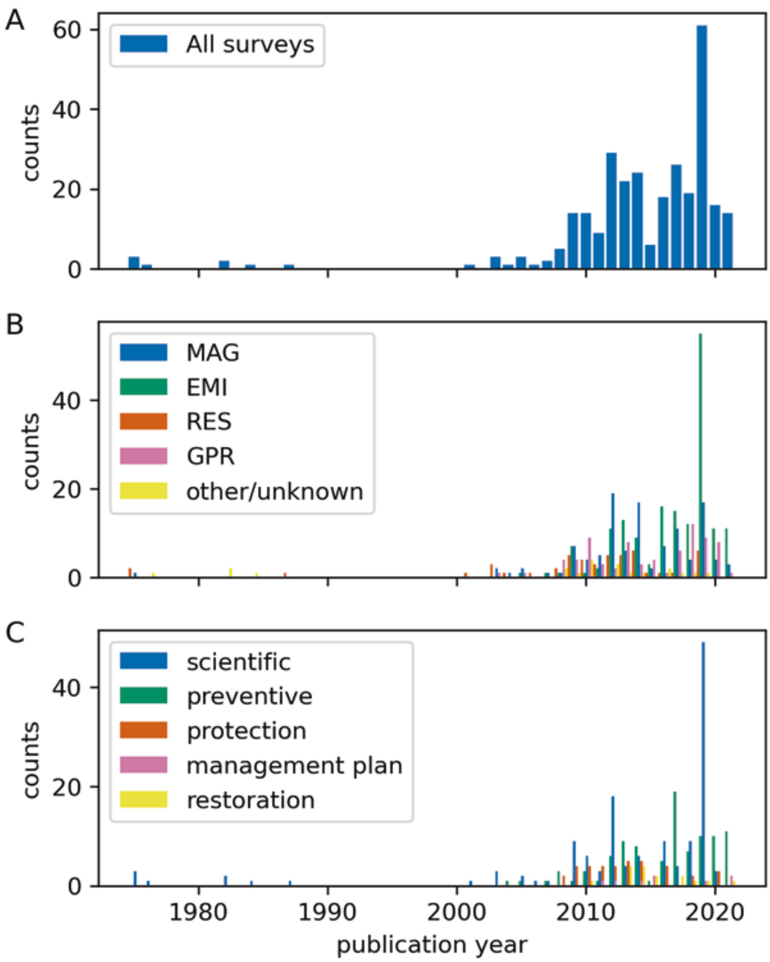

Fig. 1 (**a**) Inventoried survey projects counts and publication year; (**b**) projects counts per year of the most employed methods per year (*GPR* ground penetrating radar, *MAG* magnetometer survey, *EMI* electromagnetic induction, *RES* electrical resistance survey, *other/unknown* unknown; electrical resistivity (pseudo-)tomography, (Borehole) Magnetic susceptibility, Self Potential; (borehole) electrical conductivity, Geophysical tool for Archaeology based on Radiometric Physics, terrestrial seismic survey, Time domain electromagnetic induction, Time Domain Reflectometry and other techniques of volumetric water content sensors); (**c**) project counts per year classified according to survey objective

methods have been barely picked up in Wallonia and Brussels over the past two decades (Fig. 2a), with the exception of some projects with a scientific interest (e.g. Baltus et al., 2019; Lambot et al., 2018; Tabbagh et al., 2019). One explanation could be the limited budgets for the development-led archaeology, which is sponsored directly by the Walloon government budget. This contrasts starkly with the higher financing where the ‘polluter pays’-principle is implemented such as in Flanders.

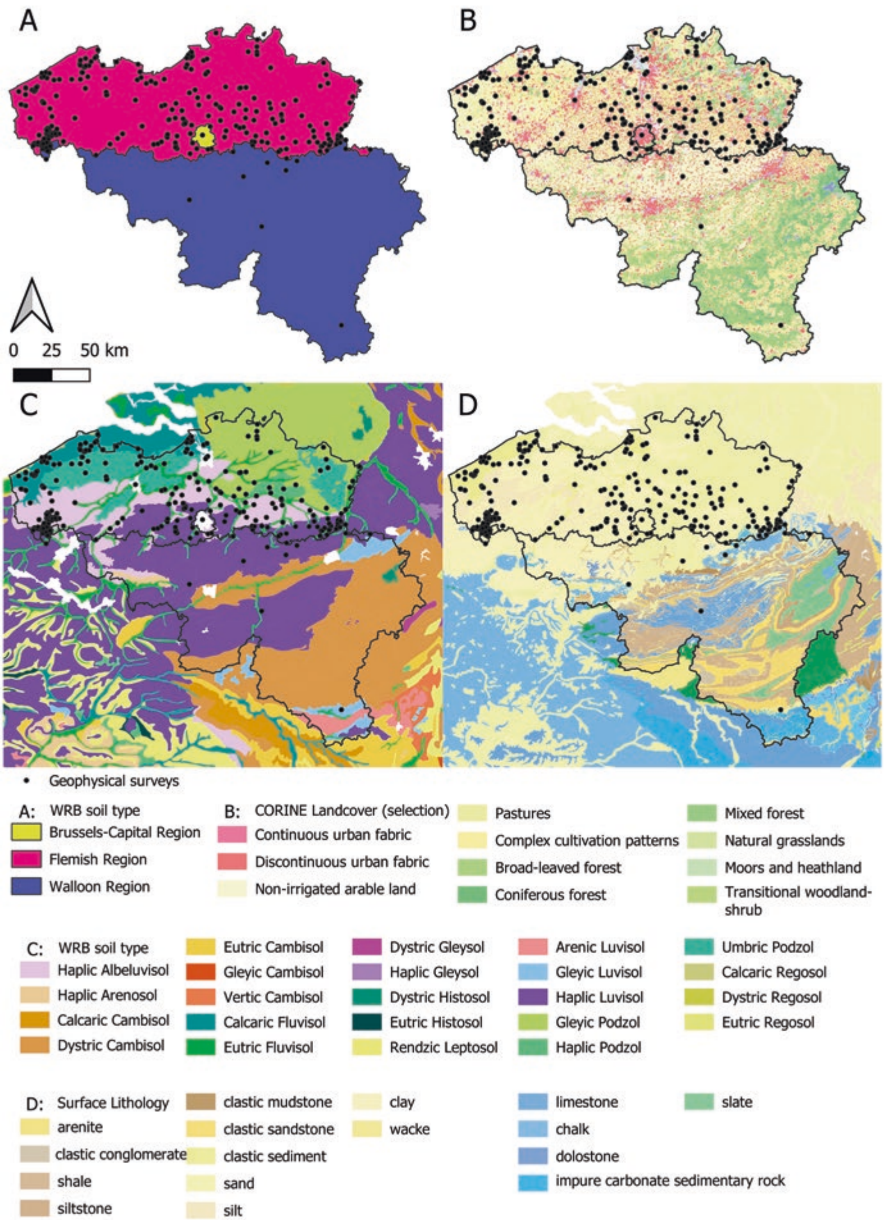

Fig. 2 Localised geophysical surveys in Belgium. Backgrounds: (**a**) Belgian regions, the highest administrative level responsible for archaeological legislation; (**b**) CORINE (CLC) 2018, Version 2020_20u1 (source + legend: https://land.copernicus.eu/pan-european/corine-land-cover/clc2018, European Union, Copernicus Land Monitoring Service 2022, European Environment Agency (EEA). (**c**) ESDA WRB soil map (https://esdac.jrc.ec.europa.eu/) (The European Soil Database distribution version 2.0, European Commission and the European Soil Bureau Network, CD-ROM, EUR 19945 EN, 2004); (**d**) 1:1M map of the Geological Unit-lithology of the pan-European Surface Geology (EGDI) (https://www.europe-geology.eu/)

Another could be that, while geophysical expertise is present in various non-archaeological academic institutes in Wallonia, research lines (and associated training programs) dedicated specifically to the archaeological application of geophysics have been lingering behind. To redress this status quo, collaborations between Ghent University, Liège University and the Walloon Heritage Agency have recently been formalised through a dedicated archaeological prospection network,[5] the PROSPECT International Thematic Network. This unique network, coordinated by Ghent University, includes more than 20 international research institutions involved in all aspects of both invasive and non-invasive archaeological prospection and aims to create enduring, stimulating environments for education and stakeholder training, interdisciplinary research development, and concrete societal and economic impacts.

In the Flanders, (student) training and developments in the use of geophysical methods in archaeology, particularly electromagnetic induction (EMI) and ground penetrating radar (GPR), started with local expertise building at Ghent University from 2007 onwards (Simpson et al., 2009; Verdonck et al., 2009). Shortly afterwards, geophysical methods started to be employed increasingly for Flemish archaeological site scheduling projects (e.g. van Kempen & Keijers, 2009) and land management (e.g. Lehouck et al., 2007) by appointment of government agencies and executed both by research institutes and independent practitioners. From 2009 onwards, the developed expertise at Ghent University enabled an increasing number of research projects, developing prospection strategies for a range of landscapes and sites, ranging from prehistoric landscapes (Verhegge et al., 2012) to medieval settlements (De Smedt et al., 2013c; Trachet et al., 2017a) and World War I battlefield remains (Saey et al., 2016a). During this period, these academic as well as site scheduling projects constituted most geophysical projects undertaken, particularly in Flanders.

In development-led archaeology, geophysical methods were applied rarely (e.g. De Smedt et al., 2011), because they were not prescribed by heritage officials, except where other methods did not perform well (e.g. Saey et al., 2016b). Legislative changes in 2016 meant that requirements for archaeological evaluations in development-led archaeology are currently created by archaeological entrepreneurs and involve early career archaeologists with basic training in archaeological geophysics. After a dip in geophysical surveys in 2015, this has led to a continuing increase in use of geophysical methods in Flanders (Fig. 1a).

3.6.3 Survey Objectives

Throughout Belgian archaeology, published geophysical surveys have mainly had a scientific objective in the past (Figs. 1c and 3a). However, their incidence varies significantly with time and depends primarily on individual project funding and researchers. For instance, about a third of all surveys with a scientific objective

[5] PROSPECT ITN: https://www.prospect.ugent.be/

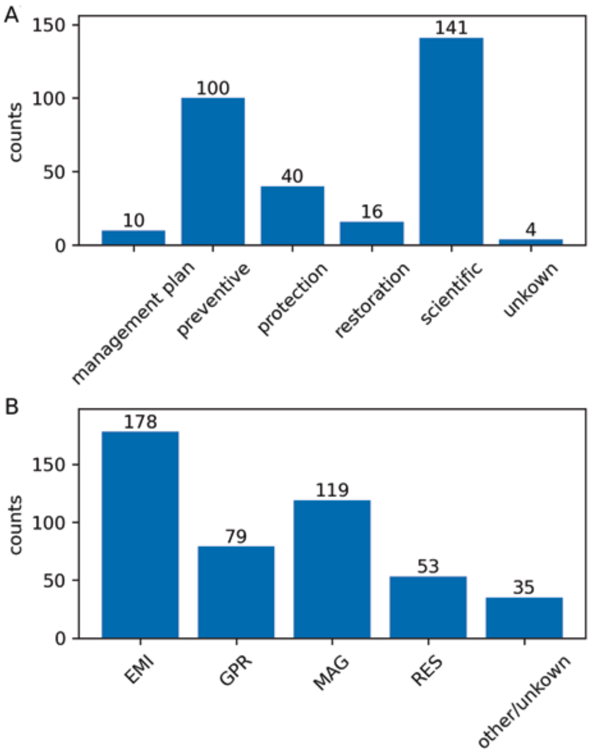

Fig. 3 (**a**) Inventoried survey project objective counts; (**b**) Inventoried survey method counts of 311 projects (*EMI* electromagnetic induction, *MAG* magnetometer survey, *GPR* ground penetrating radar, *RES* electrical resistance survey, *other/unknown* unknown; electrical resistivity (pseudo-) tomography, (Borehole) Magnetic susceptibility, Self Potential; (borehole) electrical conductivity, Geophysical tool for Archaeology based on Radiometric Physics, terrestrial seismic survey, Time domain electromagnetic induction, Time Domain Reflectometry and other techniques of volumetric water content sensors)

resulted from a single project and PhD thesis by Note (2019), creating a large peak in survey numbers in that publication year, while the number of surveys were evenly spread over the preceding 4 years.

However, development-led geophysical surveys have become increasingly frequent since 2012. Since 2016, 48 archaeological assessments (*archeologienota's*) were submitted involving geophysical survey methods in Flanders. Possibly, these numbers may rise further, because 64 applications to apply geophysical methods are submitted at the time of writing. However, this application number also include those which may well not be or have been followed by actual surveys. The mechanism behind of this increase remains unclear. It may be due to a changing policy of the Flemish Heritage agency, increasingly enforcing that geophysical methods are included in survey requirements, due to changing attitudes and training of

Table 1 Overview of yearly and total number of archaeological assessments (*archeologienota's*), the number of assessments using trial trenches and the number of assessments using geophysical survey in development-led archaeology in Flanders under the current legislation (2016–2021) until early 2022

Year	2016	2017	2018	2019	2020	2021	2022/ unfinished	Total
Total number of assessments	1006	3353	2692	2927	3115	3392	30	16516
Number of assessment through trial trenching	44	368	590	699	790	818	42	3351
Number of assessment using geophysical survey		7	7	12	8	14	64	112

commercial archaeologists writing the survey requirements, due to an increased attention to world war archaeology (cfr. infra), etc.

Nevertheless, the number of assessments involving geophysics remains marginal compared to the total number of desk-based assessments and evaluations employing trial trenches (Table 1). While site scheduling projects (Fig. 1c: protection) were an important instigator of geophysical projects outside academia, a decrease in funding equally reduced their number since 2014. Such studies have, however, been partially replaced by geophysical studies aimed at land management planning (where no immediate threat is present) and restoration projects (mainly targeting churches and their direct surroundings).

3.6.4 Employed Survey Methods

Before the late 2000s, the employed methods followed the trends in the UK because primarily experts from abroad were performing geophysical surveys in Belgium. However, the local academic developments in EMI led to a marked increase in its usage from 2009 onwards. Currently, about 40% of all inventoried surveys were done with EMI, although Note (2019) creates an outlier (Fig. 3b). The importance of EMI contrasts to other countries (Bonsall et al., 2014; Jordan, 2009; Stamnes, 2016; Viberg et al., 2011; Visser et al., 2011), which illustrates the impact of local expertise development and personal preference on geophysical survey practice. While the potential registration of two geophysical variables (electrical conductivity and magnetic susceptibility) in multiple soil volumes is certainly advantageous, the measurement volume of existing EMI configurations and lack of multi-sensor arrays limits the archaeological application potential as well. Despite a lack of strong academic focus, magnetometer survey is the second most applied survey method and remains frequently deployed, due to its survey speed and ease of use. Excluding the EMI surveys by Note (2019), magnetometer surveys would even comprise a similar share to EMI surveys. After the success of magnetometer survey in several site scheduling studies, primarily on Roman sites, it is now used increasingly in development-led archaeology carried out in the loess soils in the south-east of Flanders. Nevertheless, despite a clear potential in loess soils of Wallonia (e.g. Quick et al., 2005), magnetometer surveys remain rare here. Depending on the survey aim and environment, investigations abroad issue caution in relying only on magnetisation as geophysical detection property however (e.g. Bonsall et al., 2014; Jordan, 2009; Viberg, 2012). While electrical resistance survey was used frequently in the early years of Belgian archaeological geophysics, the number of applications has somewhat stagnated, possibly due to its labour intensity. As such, resistance survey has been surpassed by GPR, which has seen significant growth in the past 5 years. This follows international trends and is not only influenced by local expertise development (e.g. Verdonck et al., 2009) but also by an increasing number of applications in complex archaeological stratigraphies as well as a larger market for GPR outside archaeology (e.g. utility detection). In addition, the increased ability to perform mobile surveys and to collect and process data more rapidly facilitates GPR applications. However, landscape-scale GPR surveys, ubiquitous in e.g., Sweden (e.g. Viberg et al., 2020) or Norway (e.g. Gustavsen et al., 2020), are not yet applied in Belgium, despite many regions with dry, sandy soils. Other geophysical survey methods are applied infrequently and only in case-specific circumstances.

4 Archaeological Resource Management and Legal Implementation of Archaeological Prospection

The necessity for preventive, legally supported, development-led archaeological prospection became clear due to an increase in rescue archaeological projects during the late 1980s and early 1990s. During those years, rescue archaeology happened mainly in reaction to ongoing developments, while a preventive approach could embed archaeological research within the development planning process. Also during that period, Belgian archaeological heritage management was federalised into three regions: Brussels (officially: the Brussels-Capital region), Flanders (officially: the Flemish region) and Wallonia (officially: the Walloon region). Today, this regionalisation has led to different approaches in archaeological evaluations and site management, which influence the implementability of geophysical methods.

4.1 Flanders

When comparing the three Belgian regions, geophysics is best embedded in Flemish development-led archaeology from a regulatory perspective because the execution of archaeological evaluations is highly liberalised and directly funded by the developers. Nevertheless, geophysical survey is exempt from requiring archaeological permits, due to its non-invasive nature, which is favourable to scientific applications.

Although the legal implementation of development-led archaeological survey started earlier (Bauters et al., 2002; De Clercq et al., 2012a), geophysical survey specifically was included in regulations from 2016 onwards. Before that date, the use of detectors, implying metal detectors and not geophysical survey equipment, was restricted legally to permitted archaeological excavations (Deckers, 2019). Since 2016, the Flemish decree and resolution on immovable heritage includes a code of good practice.[6] This code is legally binding and describes the minimal requirements for archaeological research, including the methodological boundary conditions, and includes geophysical survey. Since then, commercial contractors both prescribe and execute archaeological evaluations. The Flemish heritage agency has adopted a coaching role with limited enforcement capabilities, which are employed primarily only after report submission. After submission, geophysical reporting, which is included within archaeological assessment reports (*archeologienota's*), is screened by Flemish heritage agency officials. Feedback is rarely given and quality controlling or correcting measures are generally absent.

The code of good practice approves of geophysical approaches to archaeological prospection in development-led frameworks, while simultaneously requiring that geophysical results are tested in all cases with other types of archaeological information to allow reliable archaeological interpretation. It can therefore only be used to select areas for further evaluation. It also states explicitly that, in itself, any geophysical survey that does not indicate anthropogenic features is insufficient to conclude that an archaeological site is absent. If applicable, the use of multiple survey techniques is preconditioned by the code. Furthermore, a geophysicist (requiring an academic diploma evidencing expertise in executing and interpreting physical measurements of soils and sediments to detect natural and anthropogenic features) determines the methodology and techniques in collaboration with the Certified Archaeologist, executes field measurements, interprets and reports them. Technical survey requirements conform to international guidelines, such as the EAC guidelines for the use of geophysics in archaeology (Schmidt et al., 2015), or refer to published literature only to a limited extend. This contrasts starkly to better established methods where technical requirements are more explicit and international guidelines and literature are included in Flemish guidelines e.g. for trial trenching (Haneca et al., 2016) or borehole survey (Van Gils & Meylemans, 2022). The requirements related to reporting are described more extensively and should ascertain reliable and comprehensive documentation of the performed research. Unfortunately, digital geophysical data archiving with the owner or a heritage depot, albeit prescribed by the code for all archaeological data, is rarely undertaken by the Certified Archaeologist. Only the geophysical survey report is archived within the archaeological assessment report.

[6] https://www.onroerenderfgoed.be/de-code-van-goede-praktijk

4.2 Wallonia

In Wallonia, an archaeological directorate was integrated within the spatial planning administration providing financing directly from the government budget for development-led archaeology in 1991. Its objectives and methods of action were confirmed and clarified by decree in 2018 and 2019. In general, the *Agence wallonne du Patrimoine* prescribes and executes archaeological evaluations autonomously. Geophysical prospection is mainly carried out for academic purposes and is seldom prescribed in any of the development-led site assessments or excavations (ca. 100/year), due to the limited government budget awarded to development-led archaeology. Therefore, it is not regulated specifically.

4.3 Brussels

In Brussels, development-led archaeology was legally implemented in 2004. As part of the building permit, the Directorate of Cultural Heritage can require developers to allow for archaeological research. This research is funded by the regional government and publicly tendered to licensed institutions, currently primarily both Brussels Universities (VUB and ULB), the Royal Institute for Cultural Heritage and the Royal Belgian Institute for Natural Sciences. Due to a lack of applications, no legislative framework for geophysical prospection has been developed yet. Indicatively, two scientific geophysical surveys for archaeology are known within Brussels to this date.

5 Belgian Landscapes and Archaeological Geophysics

5.1 Land Use

Given its limited surface area and population of ca. 11.5 million (an average population density of 375 inhabitants per square kilometre), it is no surprise that a high proportion (17%) of Belgian land-use is reserved for urban area (CORINE-continuous and discontinuous urban areas) (Büttner et al., 2004), whereas the extent of artificially modified areas (urban fabric; industrial and commercial areas; transport infrastructure; (air-)ports, dump, extraction and construction sites; parks, sports and leisure facilities) covers 20% of the country area (Fig. 2b). This (discontinuous) urban fabric forms a challenging environment for many geophysical applications. Nevertheless, 92 out of 306 located surveys were performed here (Table 2). This might be due to the location of many developments at modern town edges in combination with the coarse resolution of the CORINE landcover maps. Nevertheless, many modern Belgian cities and villages have deep historic roots making them an

Table 2 CORINE land cover classes of the inventoried geophysical survey projects. The class of a survey was determined by the majority of the pixels within the survey polygon

CORINE land cover class	Survey project count
211—Non-irrigated arable land	98
112—Discontinuous urban fabric	72
242—Complex cultivation patterns	56
231—Pastures	22
243—Land principally occupied by agriculture with significant areas of natural vegetation	18
111—Continuous urban fabric	6
142—Sport and leisure facilities	6
311—Broad-leaved forest	5
121—Industrial or commercial units	3
133—Construction sites	3
421—Salt marshes	3
123—Port areas	2
222—Fruit trees and berry plantations	1
312—Coniferous forest	1
512—Water bodies	1
No data	9

important subject of archaeological investigation. In contrast, (Early) Modern city foundations are relatively rare. More often, historic towns exhibit significant (early) modern alterations and expansions.

Non-irrigated arable land, land principally occupied by agriculture with significant areas of natural vegetation and complex cultivation patterns form the largest share of the land use (45%) and are accessible to archaeological geophysics when the land is not cropped. Intensifying agricultural practices, however, are increasingly shortening the time window for geophysical surveys. Nevertheless, more than half of all geophysical surveys (n = 172) were done on such cultivated lands. One main downside of this type of land use is the strong impact of tillage on geophysical results. Particularly the sand, sandy loam, and loam regions of Belgium have a long tradition of intensive agriculture and annual ploughing, reaching depths up to 0.6 m, which has homogenised many archaeological soil features to the naked eye, possibly only leaving geophysical ghost features (Simon et al., 2012).

Pasture makes up 11.5 % of Belgian land use. While these managed grasslands could be considered the most geophysical survey-friendly of all land use classes, only a small number of surveys (n = 22) was performed here, owing mainly to the lower suitability of most remaining pastures for modern settlement.

Forests (mixed, broad-leaved, coniferous) cover 20% of Belgium and are primarily located in Wallonia. Geophysical survey accessibility is often problematic here, but with additional localisation efforts, good results can be achieved where undergrowth is restricted (e.g. Pisz et al., 2018; Sikora et al., 2015). Nevertheless, only six geophysical surveys have happened here, leaving substantial room for improvement, particularly for land management and scientific research. Through the application of LiDAR in the past decades, many previously unknown archaeological sites and landscape features have been detected under forest. Geophysical evaluation of such LiDAR features to establish the presence and nature of these potential archaeological remains would further add to our understanding of the archaeological potential of the Belgian forests.

5.2 Soils and Geology

Any overview of the use of geophysical methods in Belgian archaeology requires understanding the geological and pedological setting in which these techniques are implemented. From the coastal plain and its polder area across the loess belt and up the Ardennes down to Belgian Lorrain, the Belgian subsurface provides a diverse and challenging backdrop for archaeological geophysics. The subsoil geology of Belgium is dominated by sedimentary rocks in the south and a thick cover of unconsolidated quaternary clastic sediments in the northern part (Fig. 2d). Based on the composition of this quaternary cover, the governing soil types and the depth to the underlying bedrock, Belgian (sub)soils can be broadly divided into six groups: (1) heterogeneous clayey, silty, sandy, and even peaty soils of the coastal plains and river floodplains; (2) sand soils; (3) sandy loam soils; (4) loam soils; (5) soils developed on shallow bedrock; and (6) urban soils. Within each of these soils, quartz makes up the bulk of the soil mineralogy and is complemented by clay minerals of which illite and kaolinite in the Ardennes (Mango-Itulamya et al., 2019) are the most common. Across the Belgian territory, these soil groups share some common geophysical characteristics. In general, the soil electrical conductivity can be considered as moderately conductive (e.g. Sillanpää, 1982) i.e. in the 10^{-3} to 10^{-2} S/m range. Exceptions exist in the coastal areas where saline groundwater is sometimes located within the first two meters below the surface (Gould et al., 2021). Such circumstances equally occur in the estuarine polder areas and along certain sea canals, where seawater seepage increasingly pressures overlying freshwater lenses, locally driving near surface electrical conductivities in the 10^{-1} to 10^{0} S/m range (Delefortrie et al., 2019; Gould et al., 2021). Since unconsolidated deposits are governed by the diamagnetic quartz fraction complemented with clay minerals, whereby naturally occurring magnetic iron oxides result primarily from pedogenesis and in absence of igneous parent materials, the shallow subsurface has an overall weak magnetic signal.

Unsurprisingly, the inventoried survey projects are located mainly on clastic sedimentary ($n = 88$), sand ($n = 74$), silt ($n = 41$), and clay ($n = 84$) geology (Table 3). Yet, few surveys occurred on consolidated geology, such as chalk ($n = 7$), limestone ($n = 3$), clastic mudstone ($n = 1$) and impure carbonate sedimentary rock ($n = 1$), despite high geophysical contrast expectations for archaeological features cut into consolidated bedrock. Consolidated geology occurs mainly in Wallonia, but the mostly sedimentary nature is not expected to hinder geophysical applications (Bonsall et al., 2014, p. 42).

Table 3 Subsoil lithology survey counts (derived from Geological Unit-lithology of the pan-European Surface Geology (EGDI)

Lithology	Count (*)
Clastic sediment	88
Clay	84
Sand	74
Silt	41
Chalk	7
Limestone	3
Clastic mudstone	1
Impure carbonate sedimentary rock	1
No data	7

When considering the topsoil (on the Flemish and Wallonian soil maps), almost one third of all surveys have occurred on loam (n = 67) (Fig. 2c: Haplic Luvisol), sandloam (n = 36) (Fig. 2c: Haplic Albeluvisol) or gravelly loam (n = 6) soil textures, employing a representative range of all available survey methods. A relatively small share of surveys happened on lighter soil textures, such as sand (n = 14), loamy sand (n = 18) and light sandloam (n = 19). The full range of techniques is represented here as well, but the limited number of GPR surveys (n = 9) on these soil textures is remarkable because the low signal attenuation of sandy soils benefits GPR applications. Particularly in the sandy soils of Northern Belgium (Fig. 2c: Gleyic, Haplic and Umbric podzol), more GPR applications are possible. On finer soil textures (clay and heavy clay), primarily of the coastal and river floodplains (Fig. 2c: Eutric fluvisol), 42 surveys were performed, mainly with EMI. Only three surveys on areas with mainly (heavy) clay soils were done with GPR, all of them on (moated) castle sites.

Aside from the geophysical properties of the soil matrix, its age is also relevant for the success of geophysical surveys. Stratigraphically younger sediments can impede detection of older archaeological remains due to their thickness or geophysical heterogeneity. A clear example are river- and coastal floodplains with (Late) Holocene sedimentation cover that protect but also impede detection of earlier archaeological remains. Furthermore, these overlying sediments often also incorporate more recent archaeological remains. The survey inventory shows that 139 geophysical surveys were performed on such floodplain sediments, where other methods are often challenged as well. In recent years, these embanked floodplains are reactivated purposefully to combat flooding (Smolders et al., 2020). This has destructive, erosive as well as protective, sedimentation effects on archaeological remains. However, it certainly hinders future prospections, which must be considered during development-led archaeological evaluations.

Similar to floodplain sediments, artificially raised soils impede geophysical detection of earlier remains, which is specifically important in the sandy soils of Flanders, since these have known significant *plaggen* soil formation since the Middle Ages (Bastiaens & Verbruggen, 1996). The thickness of this cover can be highly variable, however (e.g. Van Hove, 1997). Nevertheless, 15 surveys intersect with this mapped soil type. Many cities have also known historic and more recent

Table 4 Topsoil texture survey counts (derived from Flemish soil map 2.0 and Digital map of Soils of Wallonia)

Soil texture	Count (*)
A: Loam	67
OB: Built area	47
L: Sandloam	36
OT: Strongly altered soils	25
U: Heavy clay	21
E: Clay	21
P: Light sandloam	19
S: Loamy sand	18
Z: Sand	14
ON: Raised soils	7
G: Gravelly loam	6
OG: Debricked soil	4
OU: Depeated soil	3
L-E: Sandloam & clay	2
OC: Lost habitation	2
S-P: Loamy sand & light sandloam	1
V: Peat	1
M: Marl	1
A-L: Loam & sandloam	1
OE: Quarry	1
No Data	9

anthropogenic soil raising, impeding the detection of structural archaeological remains. Indeed 72 surveys were mainly done in areas mapped as built (code OB on the Flemish soil map and in Table 4) or strongly altered (code OT), already at the time of the soil map creation. Additionally, many areas along harbours and rivers have been raised (recently) for flooding protection, impeding geophysical detection of buried features. Seven surveys have been performed here (code OT). In addition, 10 surveys were done where the soil maps contain traces of other anthropogenic and possibly archaeological soil altering, mapped as lost settlement (code OC), debricked soils (code OG), de-peated soils (code OU) or quarrying (code OE).

5.3 *Archaeological Geophysics in (Natural) Palaeolandscape Studies*

Soils and sediments are not simply considered as matrices for archaeological remains in Belgian archaeology but are also subject of archaeological research themselves to prospect new sites and to contextualise already known sites, most often in floodplains. In the past, direct sediment and soil observations through coring or trenching were mainly employed for palaeolandscape mapping but these become less (cost-)effective as the required spatial resolutions, targeted depths and the development areas increase. While direct push sensing is one solution to overcome some of these challenges (Verhegge & Delvoie, 2021), buried palaeolandscapes are mapped increasingly using EMI. Another added value of geophysics in these studies lies in the detecting 'off-site' phenomena (e.g. land divisions and hydrographic networks), which are more easily missed through invasive methods. However, since these studies mainly aim to map natural landforms (De Smedt et al., 2013a) and larger anthropogenic land structuring features (Verhegge et al., 2017), the employed traverse spacings of these studies are somewhat larger (2–4 m) than the traverse spacings needed to establish the presence and nature of archaeological remains.

Geophysical palaeolandscape surveys occur particularly in prehistoric archaeology, e.g. along Late Glacial palaeolakes (De Smedt et al., 2013b) or in mapping peat and coversand palaeolandscapes below polders (Verhegge et al., 2016a), but also increasingly in the study of medieval reclamation landscapes (Verbrugghe et al., 2020). Also, in development-led archaeological evaluations, more precise palaeolandscape reconstructions could significantly decrease archaeological prospection costs, e.g. of archaeological core sampling (Crombé & Verhegge, 2015). For example, palaeolandscape EMI survey has already covered >4 km^2 of polders in the Antwerp harbour area.

Nevertheless, despite examples abroad (e.g. Chapman et al., 2009; Schneider et al., 2017) and suitable research questions (e.g. Usselo palaeosols as Final-Palaeolithic site context or early medieval sites below coastal dunes), GPR for palaeosol and palaeolandscape mapping is barely applied in the sandy soils of Belgium.

6 Frequently Occurring Archaeological Features or Sites in Belgium and Examples of Their Geophysical Surveys

6.1 Soil Features in Unconsolidated Deposits

The heterogeneity of the Belgian subsurface is matched by the complexity of its archaeology. In the unconsolidated deposits that govern the northern half of the country, many traces of past activity are ephemeral in their physical expression and resultant geophysical contrast. This is particularly true for (low-density) rural occupation traces throughout prehistory and well into the early historic period, which consist primarily of 'negative' features, such as postholes, humified remnants of wooden posts, pits, wells and ditches, and continues to be relevant until the late medieval period, due to scarce use of solid building-materials (natural rock and brick). Since little sedimentation has taken place outside floodplains after the start of the Holocene, the poor edaphic conditions and vulnerability to agricultural activity of the dryland settings provide little preservation potential for archaeological remains. Indeed, on many sites archaeological soil features are strongly homogenised with the soil matrix and/or only the bottom parts are preserved below the ploughing horizon. Together, this configuration translates to poorly detectable contrast for non-invasive survey approaches. Nevertheless, significant results can be obtained in the right conditions.

In the sand region, even relatively subtle features, such as organic layers within or gleying associated with the ditch fills of Bronze Age barrows (Verdonck et al., 2009) or more obvious medieval moats (Saey et al., 2014), have been mapped with GPR. Furthermore, presumed medieval soil features related to longhouse structures were detected using magnetometer survey at Snellegem (Loveluck & Tys, 2006). The origin of this contrast remains understudied, but it is one of few examples where magnetometer survey has detected assumed posthole structures in the sandy soils. Nevertheless, the ability of geophysical methods to map such low density settlements (although not in all circumstances) showcases the complementarity to standardised systematic trial trenching, which risks missing exactly these sites (De Clercq et al., 2011). Furthermore, at Maldegem-Kleit, a Roman/medieval enclosure site in a sandy soil overlaying a clayey geology, both the electrical conductivity and magnetic susceptibility data of multi-receiver EMI survey produced complementary results (De Clercq et al., 2012b; Saey et al., 2013). While the conductivity revealed the geological variation as well as ditch fills, the magnetic variations subtly revealed parts of these ditches and pits in the shallowest data layers. Since ditches were important features in land drainage and management in protohistory, Roman and medieval times in the low-lying areas of Northern Belgium, the ability to map enclosures or moated sites using their ECa contrast is valuable. However, many archaeological features at the site of Maldegem-Kleit did not exhibit magnetic enhancement, illustrating the perils of relying on one geophysical variable to study such subtle features. Interestingly, the magnetic variations did preserve within the ploughing horizon, demonstrating the danger of discarding topsoils archaeologically, which occurs all too often using trial trenching in development-led archaeology. In fact, the value of topsoil archaeology in combination with archaeological geophysics is further exemplified by the correlations between AAS and EMI survey at artefact rich sites, such as the lost harbour settlements of Hoeke and Monnikerede in the coastal plain (Trachet et al., 2017a). Even where pasture hampers walkover survey, molehill survey results have proven to correlate well to geophysical data (Trachet et al., 2017b).

In the loess region, archaeological soil features are occasionally nearly invisible to the naked eye. In one such case, a magnetometer survey was performed directly on top of an excavation surface and revealed several additional posthole structures (Celis et al., 2014), highlighting the benefits of non-standard survey strategies. Also in loess soils, a magnetometer survey at Waremme-Longchamps (Quick et al., 2005) has unveiled Neolithic enclosure ditches and longhouse features. The latter were not caused by postholes, but by domestic pits along the outer edges of the house walls, similar to discoveries in Riemst (Sevenants et al., 2011). As early as 1975, electrical resistance traverses over a cropmark feature uncovered an unmetalled road at a loess site in Sauvenière (Léva & Hus, 1975), which calls for more investigations of such features in the Belgian loess.

6.2 (Brick-)stone Features in Soft Soils

(Brick-)stone archaeological features and structures are known to exhibit better electrical and dielectric contrast within soft soils than soil features (Conyers, 2013; Gaffney & Gater, 2003; Schmidt, 2013). Within a low magnetic background, ceramic building materials demonstrate a magnetic contrast as well (Aspinall et al., 2008). While stone construction materials are widely available in Wallonia, their impact on geophysical survey results is rather limited due to a lack of surveys. However, the GPR results of the Roman villa of Mageroy illustrate the potential in mapping natural stone walled structures in a (locally) unconsolidated soil (Baltus et al., 2019). In the loamy to sandy soils of northern Wallonia and Flanders, natural stone building materials are only present in few areas and often consist of low quality sandstones. Therefore, they only started to be used in the Roman period for constructing more monumental structures and infrastructure. The Roman age also signifies the first use of ceramic building materials. As such, successful magnetometer surveys were performed on several vicus sites in the loess region (Charlier et al., 2001; Wesemael & Nicholls, 2014). In the Middle Ages, stone building materials restarted to be used in the 10th century in northern Belgium, mainly for monumental structures (e.g. churches). From the 14th century onwards, particularly brick masonry is considered a more common building material (Debonne, 2015) and smaller quantities were also used as footings and foundations of common wooden structures. As such, geophysical methods are widely used in (post-)medieval archaeology, for instance charting rural buildings in the outer court of the abbey of Boudelo using EMI magnetic susceptibility (De Smedt et al., 2013c), as well as monumental castles (Simpson et al., 2009).

Thanks to the success in mapping (brick-)stone remains, appropriate survey strategies are readily available to map such sites in soft soils with magnetometer survey, electrical resistance survey or ground penetrating radar survey, depending on the background soil and research questions in academic research, in site scheduling and increasingly in development-led archaeology.

6.3 Complex Urban Stratigraphies

In Belgium, complex stratigraphic sequences primarily occur in urban settings. Few cities, such as Tongeren (Wouters et al., 2019) and Tournai (Devos et al., 2020) have a significant Roman stratigraphy . However, many urban centres developed during the Middle Ages (Devos et al., 2020). As such, 58 historic city centres are protected archaeologically (Archeologische Zone) in Flanders. However, due to their continuous habitations, structural remains are frequently covered with thick deposits of urban waste as well as modern (underground) infrastructure. Therefore, historic city centres form complex environments for geophysical applications. Nevertheless, 26 surveys have already happened within the border of protected historic medieval town centres in Flanders. Unsurprisingly, 18 of these surveys were done with GPR, due to the complexity of the vertical stratigraphies. A significant proportion of these are church studies where the subsoil is mapped in the framework of renovations. The city centre of Brussels has only seen one geophysical survey on its central square, but it did reveal several basement structures illustrating that the square did not always function as such (Tabbagh et al., 2019). On the other hand, a GPR survey on the quays of Antwerp illustrated the difficulties in acquiring useful results in urban settings (Verdonck, 2010).

6.4 World War Battlefields

The well-inventoried historic aerial photographs of the World Wars form a significant resource for desk-based research. Geophysical methods (primarily EMI and magnetometer survey) are used increasingly as research tools by themselves or as an intermediary step before invasive trenching to accurately locate and check the presence of photographed traces. As such, an important cluster of geophysical research projects is located along the frontlines of World War I. The work of two archaeological geophysicists, P. Masters (Masters & Stichelbaut, 2009) and particularly N. Note (e.g. Note, 2019; Note et al., 2019; Saey et al., 2016a), has resulted in a marked concentration of surveys here. Evaluating World War I remains forms an important part of archaeological practice and development-led archaeology in this region, not only for heritage management but also for unexploded ordnance detection (UXO) and retrieval of human remains. Since the relatively recent age of the conflict, remains are usually well preserved. In addition, the soil impact is large, particularly where the frontline was relatively stable for longer periods and infrastructure was dug deep into the subsoil, leading to significant electrical contrasts. Furthermore, the materials used are very often (at least partially) ferrous, increasing the magnetic signal, which can be both supportive, if associated with features, and disadvantageous, if creating survey noise. As such, primarily EMI and magnetometer survey have identified trenches and associated structures, bomb and mine craters, military camps, tank remains, etc. (Note, 2019 and references therein). Following the academic research results, the implementation of geophysical methods in development-led archaeology has already started on these site types and is projected to grow in the future. Despite the absence of a legal framework that encourages active grave detection or UXO detection, EMI data filters to detect large metallic objects (Saey et al., 2011) and spatial analyses integrating EMI data and historical photography have been developed (Note et al., 2018). Integrated geophysical surveys for development-led archaeology, grave and UXO detection happen on an *ad hoc* basis on World War sites.

7 Discussion and Conclusion

7.1 From Academic Research Tool to Development-Led Archaeology

While pioneers made significant developments, Belgium's reliance on expertise in archaeological geophysics from abroad limited applications until roughly 15 years ago. Since then, particularly in Flanders, local expertise development in EMI and GPR survey has led to increased geophysical applications, including other methods. Especially in the widespread use of EMI, Belgium is spearheading internationally. However, Wallonia and Brussels are still seeing few geophysical surveys. Nevertheless, the different legal implementation of the Valletta convention could allow wider prescription and application of geophysical survey by the regional governments here if expertise is obtained (in Flanders or elsewhere) and government budget constraints allow it.

Early geophysical applications were mainly conducted in the framework of academic research or for site scheduling. Nowadays, academic research projects incorporate geophysical methods in a systematic way and as part of environment-adapted multi-method prospection protocols in landscape archaeology. In development-led archaeology, on the other hand, geophysical survey is only used in a negligible share of evaluations. Still, these applications have risen significantly over the past decade in Flanders, despite an awkward legislative implementation in commercial archaeology. These applications, and their success, unfortunately remain highly dependent on the individual archaeologist commissioning, and the geophysicist executing the survey. Moreover, these surveys are often stand-alone operations with little targeted invasive evaluation, feedback nor a full integration with other (archaeological) survey methods applied, most likely because of financial reasons, time constraints, lack of communication, etc.

Geophysical methods do not only need further integration within the development-led archaeological project management. Another pathway to a more widespread implementation could lie in drawing closer to the application of geophysics in other types of project management. After all, similar geophysical methods are also used in applications such as the detection of unexploded ordnance, utility mapping, groundwater studies and precision agriculture. Data sharing between these fields, which hinges on increased awareness and open cross-disciplinary and -institutional communication, could create mutual benefits.

7.2 Guidelines, Commission, and Training in Development-Led Archaeology

Through the results of the past years, the need for international guideline implementation is showing increasingly to enable a fair market and achieve optimal results. Nevertheless, the rigid approaches used in Flemish commercial trial trenching and borehole survey illustrate both the benefits and risks of standardisation. Since universally applicable technical methodologies are nearly impossible to make, it would be more practical to follow a discursive approach as suggested by Schmidt (2019) and to implement the EAC Guidelines for the use of geophysics in archaeology (Schmidt et al., 2015) in the code of good practice in Flanders. This should result in more detailed, prescriptive project specifications than at present.

However, the EAC guidelines recommend involving expertise of archaeological geophysicists in designing project specifications. In the future, this could fit well within current development-led archaeological practice in Wallonia and Brussels. However, this would not fit well within the current practice in Flanders. Here, archaeological briefs are designed commercially, cheaply and in a relatively standardised manner. An archaeological contractor decides if geophysical survey is applicable when writing the desk-based assessment and selects further research measures, often without involving geophysical experts. In addition, geophysical survey is often perceived as an additional cost, since invasive prospection has to be applied as validation anyway. Deviating from the standard code of good practice, the commission of a geophysical survey increases the cost of designing an archaeological brief as well as executing an evaluation. Therefore, geophysical and other non-invasive methods are rarely prescribed within this commercially driven rigorisation of survey methodology in a development-led archaeological heritage management environment.

Moreover, if geophysical survey is used at all, the most appropriate methods are not always applied. Hence, further methodological education and training of archaeologists is required as well. This has to be combined with further expertise building to establish integrated survey protocols and make geophysics a fully-fledged tool in the non-invasive assessment of the Belgian archaeological record.

7.3 The Importance of Prior Knowledge

Whilst the geology of Belgium is supportive to many geophysical applications, its soils are highly variable and require significant geophysical expertise for optimal results. The complexity of land use amplifies this necessity, because it might impede geophysical survey results. Inherent to geology and soils in northern and central Belgium, the nature of settlement soil traces (e.g. postholes) is rather ephemeral in the absence of deeply dug archaeological traces, particularly in the absence of (brick)stone.

Considering the risks involved in missing archaeological heritage of low-density soil feature sites (unrecorded destruction), a general development-led application of geophysical survey replacing or as efficient as systematic trial trenching could not be advocated. The past results have shown that if archaeological and geophysical prior knowledge is available about the nature and setting of a site, well-reasoned decisions can be made to use geophysical methods efficiently in combination with invasive methods, generating added knowledge values.

However, development-led applications without sufficient prior knowledge on both the archaeology and the (natural) background of the site are ill-advised as argued by Hulin and Simon (2020). Indeed, in many development-led projects the archaeological remains as well as their geophysical signal are indeterminable at the start of the project.

If investigated sites are not threatened (e.g. academic research, protected site management or site scheduling studies), a landscape-based combined array of non-invasive studies should always be given preference, if they can answer the research questions and/or optimise later invasive research. In these cases, the threat of non-detection is smaller and often only resulting in reduced archaeological scientific knowledge, rather than unrecorded destruction.

7.4 Benefits of Geophysical Methods in Archaeological Prospection

While the cost-effectiveness for coverage of geophysical methods in comparison to systematic trenching is often argued, this can only be achieved if significant prior knowledge of the site's archaeology and pedological background is available (Hulin & Simon, 2020). Without this prior knowledge, multi-method and high-resolution geophysical survey would still need to be complemented with systematic trial trenching to evaluate the broadest range of possible archaeological remains, increasing costs significantly. However, recording geophysical variables in addition to visual inspection of the trench surface would include those 'ghost' features with a geophysical signal but invisible to the naked eye or those preserved in the topsoil.

Since geophysical methods are mostly non-destructive, their application could be beneficial as a risk management tool to avoid the damage of valuable archaeological remains in cases where development plans are adaptable. However, the selection of 'empty' areas for adapted development plans still require further evaluation because a lack of geophysical evidence of archaeological remains cannot be interpreted as an absence of archaeological remains.

In addition, certain pedological or geological environments (e.g. coastal regions or fluvial floodplains with shallow groundwater tables) are particularly challenging environments for standard systematic trial trenching or require costly coring surveys. In these circumstances, geophysical survey can guide these efforts and increase the (cost-)efficiency of these actions.

Specific types of archaeology, such as Neolithic settlement traces on sandy or loess soils, are also hard to detect through trial trenching, due to a lack of visible contrast or the sparse spatial layout of the features. If the detectability of such features is established, the density of geophysical measurements facilitates mapping structures and site layouts.

Indeed, a lack of visible contrast does not necessarily exclude geophysical contrast or vice versa. As such, predicting geophysical contrast is essential to optimise survey choices further in the future (e.g. Verhegge et al., 2021). Ongoing geophysical research of archaeological features as well as natural soil variations aims to derive geophysical contrast from (dynamic) soil properties quantitatively and may prove valuable (Boddice et al., 2013; Fry, 2014; Schmidt et al., 2017; Schneidhofer et al., 2017). However, geophysical experts can currently also provide qualitative answers here. Further integration of geophysical data with other methods beyond the qualitative level is currently investigated academically and may lead to more widespread application in the future. However, this will require including geophysical expertise in projects in a more comprehensive manner, beyond the non-invasive, prospective phase.

7.5 Data Archiving and Publishing

The analyses of this paper were based on a superficial (metadata) analysis of an inherently incomplete survey record. Not all surveys were fully reported and not all reports were publicly available. However, this has improved in Flanders, where development-led reports are publicly available since 2016. More in-depth analyses require at least access to all reports and preferably the (raw) survey data themselves. This currently impossible of a lack of archiving of old reports and geophysical data in general.

Under current practice, the inventory of this significant resource risks becoming insurmountable, as has happened to the Belgian oblique aerial photographic record. Without proper data archiving and publishing strategies in place, gathering legacy geophysical survey data in person is currently time consuming and sometimes impossible (see Bonsall et al., 2014), often preventing reuse of collected datasets. Although international archiving guidelines exist (Schmidt & Ernenwein, 2013), few guidelines are implemented except for the limited prescriptions in the Flemish code of good practice (Hacıgüzeller et al., 2021; Lombaert & Vanstappen, 2014). The necessary data infrastructure is currently absent. In addition, while legislation obliges archiving of the digital and physical archaeological ensemble either in archaeological archives or by the owner, this is rarely enforced (and therefore scarcely practised) in geophysics. Thus, geophysical data archiving and publishing relies on the goodwill of the archaeological geophysicists themselves.

7.6 *Archaeological Feedback*

To further deepen analysis of geophysical contributions to archaeological research (questions), the often-linear trajectory in development-led archaeological evaluations (desk-based assessment > prospection > excavation > archiving) needs to be left and an archaeological feedback loop created by both archaeological geophysicists and field archaeologists. On the one hand, this could inform geophysical experts about the reliability their interpretations and bolster future interpretations. On the other hand, this provides the archaeologist with improved interpretations as well as a better understanding of archaeological geophysics. This needs to happen at least after invasive investigations but preferably during them to allow for in situ- or excavation surface geophysical measurements. Only in these circumstances, the actual contribution of geophysical survey to answering archaeological research questions can be assessed in more depth.

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