The many challenges of digital and computational archaeology

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The Many Challenges of Digital and Computational Archaeology

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Mevrouw de Rector Magnificus, leden van het bestuur van de Faculteit der Archeologie, waarde collegae, geachte toehoorders,

Dear students, friends, and family,

The branch of archaeology for which we now use the attributes 'digital' and 'computational' has a long history going back to the 1950s but has gained momentum in the past two decades. Tanasi even calls Digital Archaeology 'one of the hottest fields in the galaxies of disciplines focusing on the study of the human past' (Tanasi, 2020, p. 22). This exciting development has now culminated in the establishment of the first chair of Digital and Computational Archaeology in the Netherlands. A remarkable achievement, and in this speech, I wish to duly acknowledge all who made this possible, some of whom are here among us.

Yet as fashionable as Digital and Computational Archaeology is, it is also a challenging discipline – although in a productive and inspiring way. I want to use this opportunity to elucidate a few of these challenges and show how they advance archaeological research into the human past.

Defining what we study

With this heading I am citing Dylan Davis, who, in his article of the same title (Davis, 2020), highlighted the importance of clear and consistent definitions in archaeology. While this is hardly controversial, it is not always easy to achieve. In the case of 'Digital Archaeology', both the subject and the term have been around for decades (Huggett, 2014), and yet everyone seems to have a different idea and expectation of what it is and what it does. Morgan calls this 'the porous and shifting nature of digital archaeology' (Morgan, 2022, p. 214). The more recent term 'Computational Archaeology' only adds to the confusion. It is a challenge to define what we study. Today I offer my own perspective, thereby also explaining why we named the new chair as we did.

Simply put, 'Digital Archaeology' means using digital data, tools, methods, and media for the purpose of archaeological research. Such a basic definition is incredibly broad and encompasses many different digital elements – from simple spreadsheets for the recording of lab data to sophisticated multi-dimensional pattern recognition, and from digital photography for field recording to immersive virtual museum exhibitions. While some digital technologies are so pervasive today that using them has become general knowledge, others require advanced technical skills based on years of training and experience. No archaeologist can master all these technologies. That is why the specific activities in which digital archaeologists around the world engage differ widely according to their skill sets and personal preferences.

Consequently, Digital Archaeology programmes in higher education around the globe have quite different foci under the same or similar titles. It is thus no surprise that prospective students often struggle to choose the right institute to study Digital Archaeology. Most such programmes focus on technologies that require special skills, beyond what is taught in the core curriculum of the underlying archaeology programme. However, where the line is drawn between general skills and special skills, and between the core curriculum and a specialisation, differs widely among archaeology institutions, depending on their backgrounds, traditions, and choices. Like many methodological subjects, especially in the archaeological sciences, Digital Archaeology is in constant competition with other subjects for a place at the high table of the core curriculum. Here in Leiden – thanks to the enduring efforts of my predecessor, Hans Kamermans, my colleague, Milco Wansleeben, and others, as well as thanks to the open minds of programme directors and faculty board members over the past decades – subjects such as exploratory statistics, GIS-based spatial analysis, and predictive modelling are a core part of our undergraduate programme, whereas elsewhere they are considered optional, special skills rather taught to graduate

students. In Leiden, this enables us to offer education and training in more sophisticated digital methods and techniques at the graduate level, which I will further address in a minute.

The term 'Digital Archaeology' may also be confusing because today almost all archaeology is digital in a sense. We all use digital photography, spreadsheets, word processing software, and more for even the most basic fieldwork. In this sense, the term is so broad that it is almost meaningless. We still use it, because it is a well-established and attractive brand that holds many promises, as shown in a recent review (Lambers, 2023). But, considering its increasing redundancy, I am convinced that we will drop it at some point in the future, thus recognising 'a state of normality that has existed for at least 20 years' (Costopoulos, 2016, p. 1). All our students are digital natives anyway, for whom the line between analogue and digital is blurred at best.

In this context it is interesting to note that the attribute 'digital', while still relevant in the Humanities (e.g., Digital History, Digital Linguistics), is hardly used anymore to denote disciplines in the Sciences. There, it has become self-evident, and thus, redundant, long ago. To a lesser degree, the same is true for the Social Sciences. In both fields, the attribute 'computational' is much more common (e.g., Computational Biology, Computational Finance).

This brings us to 'Computational Archaeology', the second part of the denomination of the new chair. This term has gained much traction in archaeology in recent years. We also chose it for the master's specialisation that we are introducing this academic year. So, what does this more recent term mean?

In our research and teaching, we focus on the use of computational method and techniques that help open up new avenues for archaeological research, enabling investigations that are not possible with conventional means, 'to go beyond what we do and know' (Hageneuer, 2023, p. 80). For this purpose, we build on the theory and practice of Computer, Data, and Information Science. Examples include:

- Pattern recognition in high-dimensional data – e.g., to detect archaeological proxies in multimodal remote sensing data;
- Mixed reality – e.g., to virtually enrich the real-world context of an excavation with field data recorded in previous years; and
- Simulation – e.g., to test hypotheses on the impact of different environmental, social, or economic factors on the development of ancient societies.

I will present more examples from our own research in the next section. While none of these methods and techniques are new or cutting edge in the fields for which they were originally developed, archaeology proves to be a challenging application due to its complexity, which is often related to data scarcity, data heterogeneity, and high levels of uncertainty. In our experience, this makes archaeology an attractive partner for experts and developers from Computer Science, Data Science and related disciplines, on whose collaboration we regularly rely. Leiden University has established effective networks to facilitate such interdisciplinary collaboration, such as the Data Science Research Programme (DSO) a couple of years ago, or the current Society Artificial Intelligence and Life Sciences (SAILS) network. I am grateful for the opportunities afforded by these networks.

Engaging with these technologies and contributing to these networks in a meaningful way requires a certain level of computational literacy on our side, at least to the degree that we can have meaningful communication with our partners. While archaeology is usually not at the forefront of the latest technological developments, compared to other disciplines from the Humanities and the Social Sciences, it has been

a tech-savvy one for a long time. We now have more and more practitioners in our ranks with a solid education and training in programming, algorithms, and modelling. Beyond mere adaptation, this enables us to actively take part in the development of innovative technologies and methods tailored to our own needs, on a level that makes our solutions also interesting and relevant for other disciplines. The fact that our recent methodological research involving computational methods (cited below) has been cited well beyond archaeology in fields such as engineering, geography, marine biology, health, ecology, art history, sociology, and education is a good example. Thus, in line with Llobera's vision (Llobera, 2011), we are not just following technological trends, we are also giving them shape and direction. In a sense, we have moved up a level. In my view, this is the main difference between Digital and Computational Archaeology, and the reason 'Computational Archaeology' is likely to stay.

This entails a responsibility in terms of education. In the past, this advanced level of computational literacy was grounded primarily in personal interest and initiative of individual researchers who acquired that literacy in often informal settings and in unsystematic and creative ways. Now it is our task to provide a formal education on these matters, to build this literacy structurally into our curriculum (Schmidt, 2023). That is what we are trying to do with our new master's specialisation. To see whether we succeed, we will need to continuously hear from our students. This year's complete overhaul of our master's specialisation is the result of such feedback over the past years (Lambers, 2023). So, dear students, know that you do not just need to endure our programme, you can actively shape it!

Developing methods, building tools, changing practices

So what is our research focus in digital and computational archaeology? The core business of our field has always been to adapt or develop enabling technologies, methods, and concepts that make archaeological research and heritage management easier, better, more comprehensive, more accessible, and many other things. Well-known examples include digital field recording of excavations, spatial databases of archaeological projects that combine data management, analysis and visualisation, and virtual replicas of valuable museum artefacts. Ideally, we strive to go beyond current practice and open new avenues for research that have not been available before. Being archaeologists, our ultimate goal is always knowledge gain, in quantitative and qualitative terms, about the human past – not just more, but 'new information' (Llobera, 2011, p. 217), and 'new knowledge' (Huggett et al., 2018, p. 46).

I want to cite two examples from our own research here, of which I am particularly proud, since they are the first PhD projects that I supervised in Leiden. Shortly after I took over the responsibility for the newly established research group of Digital Archaeology from Hans Kamermans, my dear colleague, David Fontijn – whose premature passing last year is still felt heavily at the faculty – had a wonderful welcome gift for me: Two PhD positions in the inter-faculty Data Science Research Programme, partly funded by our faculty. Then a member of our faculty board, David was responsible for this unusual investment, and for making it a success. Data Science not being his core expertise, he gladly handed the latter task to me but stayed actively involved until the successful completion of both PhD projects two years ago, which shows his dedication until the end. For me, it was a fantastic opportunity to shape the profile of the new research group. So, together with Milco Wansleeben, we designed two ambitious PhD projects: One continuing Milco's previous research in text mining, the other one building on my own line of research in remote sensing. We then hired two talented PhD candidates, who exceeded all our expectations.

In the first project, Wouter Verschoof-van der Vaart developed an AI-based multi-class archaeological object detector for

LiDAR data from the central Netherlands (Verschoof-van der Vaart, 2022). In other words, he used Convolutional Neural Networks (CNNs) to automatically detect and classify different types of archaeological landscape features in high-resolution digital terrain models of the Veluwe. His research was groundbreaking in a number of ways:

- His workflow almost doubled the number of known archaeological objects across the Veluwe;
- It was the first detector that was able to recognise different classes of archaeological objects in one go;
- He integrated Deep Learning into the usual GIS environment common in archaeological practice; and
- He devised productive and efficient ways of integrating expert knowledge into the workflow.

Somehow, Wouter even found time to make significant contributions to our Citizen Science project, Heritage Quest, that dealt with similar research problems, and we were able to design an innovative conceptual framework for the integration of AI and Citizen Science approaches in future research (Lambers et al., 2019). It is thus no surprise that this research yielded the most highly cited publications of our group, and that we are going to continue this line of research with the latest ideas and new partners at an even larger scale. A major grant application is currently in preparation.

In the second PhD project, Alex Brandsen developed an AI-based semantic search engine and portal that gives access to a huge corpus of unpublished excavation reports from Dutch archaeology (Brandsen, 2022). These reports stem from development-led archaeology, which constitutes over 90% of archaeological research conducted each year in the Netherlands. They contain invaluable information about the human past in this country, and yet, they are consulted and used much less frequently than they should, since accessing and searching them has always been difficult and cumbersome. Alex's search engine and portal make all this content easily available, allowing meaningful, structured searches, and giving easy access to the original sources. This is a quantum leap for archaeological research in the Netherlands, which can now be undertaken in a much more comprehensive, informed, and enriched way.

The significance of this research was recognised by a major grant that we received from the Dutch Research Council's (NWO) *Archeologie telt* programme. In the current follow-up project, a lot of data has been added to the search portal, including published literature, sources from neighbouring countries, and sources in English and German. The semantic search has been extended to those languages as well, making this, to our knowledge, the most powerful and comprehensive search engine for archaeological literature of a given region in the world. In collaboration with the Cultural Heritage Agency of the Netherlands (RCE), we are currently exploring ways of perpetuating and further extending this service for the benefit of the Dutch archaeological community and beyond.

Both projects show that we continue the good tradition of our research group, as established by my predecessor – to conduct relevant research that impacts archaeological practices both in the Netherlands (e.g., Kamermans et al., 2009) and, through collaboration with international partners, outside its borders. Feedback from the field is crucial to shaping the direction of this research, and in both projects we eagerly collected this feedback through dedicated workshops, case studies (Brandsen & Lippok, 2021) and other means.

As you will recall, both projects started in an unusual way, in that our faculty committed a small portion of its annual budget to partially pay the salaries of the two PhD candidates, while the other half was covered by the Data Science Research programme from central university resources. It was an investment, one that paid off. Not just in financial

terms – the major grant mentioned outweighed the initial investment – but also in terms of impact on the field. Such investments have since become much more difficult due to the challenging financial situation, which is clearly a loss regarding the potential gain. I am therefore glad to see that my dear colleague, Tuna Kalaycı, who joined our team in 2020, is currently supported by another internal grant available to assistant professors, a so-called *startersbeurs*. Among other things, his cutting-edge research explores the huge potential of robotics for archaeological fieldwork and lab work. In conjunction with AI, the idea is to automate routine tasks, but also to facilitate new kinds of research not possible with current means. His research could be considered high-risk, but I prefer to focus on the high gain that it is likely to yield. Needless to say, his line of research also opens many opportunities for interdisciplinary collaboration, e.g., in the SAILS network and beyond.

Considering these examples, it is clear that we can develop powerful new ways of conducting research in computational archaeology with rather moderate means, in particular compared to other disciplines. It is therefore my hope and my mission that the faculty and the university continue to invest our own resources, even limited ones, in promising new lines of research. Such initial investments have the potential to open up more substantial funding opportunities. They should therefore not be a taboo, especially considering the expected budget cuts.

Questioning archaeological practice

As in other domains, AI applications in archaeology such as the ones cited above have been criticised for their lack of transparency. While their results are often outstanding, it remains unclear how they were achieved. Deep neural networks, the most commonly applied tool, are as opaque as they are complex. We know how they work in principle, but we do not know what they do in specific cases. This 'black box' problem undermines the principles of the scientific approach. A whole research field has evolved that is trying to shed light on the inner workings of these black boxes, striving for explainable and thus, trustworthy AI, and we are slowly getting better at understanding what is going on. So far, archaeology has only played a marginal role in this endeavour, but awareness of the problem is increasing, as are attempts to develop archaeology-specific approaches to the use of AI (e.g., Huggett, 2021; Tenzer et al., 2024; Vadineanu et al. 2024).

However, I want to focus here on a corollary of the AI black box problem that has received less attention, although it is even more pervasive in archaeology – and probably in other domains as well. A recurrent experience since I started working with AI a decade ago has been that it tends to question the expertise of its user. We measure the performance of AI models by applying them to benchmark datasets. In remote sensing, these can be archaeological sites whose existence, location, extent, function etc. have been confirmed through field survey, excavation, or other lines of evidence. In text mining, these can be classifications of terms made by experts based on established rules. In some domains, such expert benchmark datasets are even called the 'gold standard'. When we give an AI model the same classification task, we measure for example the percentage of correctly identified instances of the pre-defined classes, which indicates how well the model works.

Yet AI models can be quite merciless in exposing flaws in our benchmarks. When we used deep neural networks to find sites in remote sensing datasets, there were cases of knowns sites that were not found and, when checked, indeed could not be confirmed, for example because they were destroyed, had the wrong coordinates, or their original record, when checked, proved questionable. At the same time, the AI model found obvious sites that all previous research had overlooked.

It can be quite embarrassing and annoying to have one's own expertise questioned in this way by an anonymous AI model. But there is a lot to gain if we accept this challenge. Dave Cowley has repeatedly pointed out that the human brain, including the academic expert mind, is as much a black box as a deep neural network (Bennett et al., 2014; Cowley, 2012, 2016). What has led experts to certain classifications in our benchmark datasets is often far from clear, transparent, or consistent, and this results in flawed datasets. That is why I no longer regard benchmark datasets based on expert knowledge as 'gold standard'. Rather, imperfect as they are, they can be the starting point of an iterative feedback loop in which experts, AI models, and also citizen scientists (Bourgeois et al. forthcoming) recurringly challenge each other, building on their specific strengths, jointly striving to co-create better data. This humbler view on our own expertise enables us to achieve enriched, high-quality data in the long run.

The examples I cited so far dealt with supervised learning, in which experts define archaeological classes based on their knowledge and use AI models to classify sites, artefacts, words etc. In his recent master's thesis, Guilherme D'Andrea used supervised learning to re-create an established pottery typology from the Bronze Age in West Asia (D'Andrea Curra, 2022). The machine learning methods that he employed revealed some flaws in the benchmark dataset, such as misclassified artefacts or questionable class definitions, which helped him to better understand the pottery assemblage he was analysing. But the real challenge is only about to come. Continuing this line of research in his ongoing PhD project, he is now using unsupervised learning to study known pottery assemblages. Unsupervised learning means that we do not start from predefined classes. Rather, we let the AI models define classes solely based on observed similarities and patterns in the quantitative dataset. As his first results show, this is likely to reveal interesting connections between groups of artefacts that we have overlooked and can potentially suggest alternative classification schemes to the established ones. If and how these classifications are meaningful in cultural, social, and historical terms remains to be assessed and interpreted by the archaeologist, but it is quite an exciting prospect to be challenged in this new, potentially disruptive way.

A prerequisite for such an approach is transparency, openness, and reproducibility on all levels. Even though I am happy to see fervent advocates of Open Science in archaeology at our faculty (e.g., Bartholdy, 2024), we have a long way to go before this becomes the established standard in our field. Agnes Schneider's ongoing PhD research deals with reproducibility of archaeological interpretation in geophysical prospection, a widely used tool in archaeological surveys to explore sites in non-invasive ways. It is astonishing to see to which degree the human black box dominates this well-established field, and how challenging it is to achieve even basic levels of openness and reproducibility in the archaeological interpretation of geophysical data. But Agnes is making good progress (Schneider et al., 2023) and is about to present her first results soon. Open Science is just good science (Tennant, 2019)[1], it is simple as that, and fostering Open Archaeology has the potential to transform our discipline (Schmidt & Marwick, 2020). So we will continue to strive for more openness, transparency, and reproducibility in all our work.

Embracing ambiguity

As clear and straightforward as my previous statement is, the caveat is that such clearness is not always easy to achieve. This is true for pursuing openness, but also in other regards. In archaeological research and heritage management, we often face dilemmas or have to find a balance between conflicting

1 Or, at Leiden University, even better science, see https://www.universiteitleiden.nl/en/news/2021/02/open-science-means-better-science.

goals. I want to mention a few such situations here, but also show how ambiguity can be beneficial and productive.

As mentioned previously, we have made great progress in detecting archaeological sites in remote sensing data. On the Veluwe, we were able to detect and map hundreds of sites this way that had remained hidden despite decades of research. Similar projects are going on around the world and have led to amazing discoveries (e.g., Prümers et al., 2022; Rostain et al., 2024). However, if we share all the exciting new data openly to enable research and preservation, we may also expose those previously hidden sites to the risk of illicit excavation, looting, and destruction. In many regions of the world, this risk might be higher than on the Veluwe, but even there it is not zero. As all good things, openness can be abused, and there is no one-size-fits-all solution to prevent it. But we need to find good compromises on a case-by-case basis.

Another example from the wider field of archaeological sciences may further illustrate the dilemmas that we often face. Some time ago I attended a lecture about the study of human remains from an archaeological site, a long-established and respected branch of archaeological research with high scientific standards. However, in the talk, the speaker did not show a single picture of the investigated bones. The cited reason for their approach was respect for the deceased. So, due to ethical concerns, the audience did not get to see the underlying data and thus had no way of assessing for themselves the accuracy and plausibility of the speaker's analysis and interpretations. In my view, such an approach undermines scientific rigour and transparency and does not do the deceased any favours, since the presented narrative about their lives and deaths cannot be questioned or critically reviewed. Yet I am torn, since I also understand the speaker's intention here, considering archaeology's long history of dealing with deceased human beings in unethical and abusive ways. Clearly, we need to strive for better ways to reconcile openness, scientific rigour, and ethical conduct, ideally not sacrificing one for the other but finding a good middle way. However, that is more easily said than done, and again, there are no simple solutions in sight.

Luckily, there are also cases where a lack of clarity – in other words, ambiguity – can be productive and illuminating. Let us return to archaeological remote sensing – clearly one of my favourite subjects. The rich new data that we produced about archaeological sites on the Veluwe is different from earlier data not just in quantitative, but also qualitative terms. We started from a database where all entries were marked as archaeological sites. This implies that we can distinguish what is archaeology and what is not – a binary conceptual framework that is the basis for archaeological databases around the world. Our new data, on the other hand, contains uncertainty and ambiguity. Each site comes with a probability of belonging to its designated class. This probability is either calculated by our automated classifier, or it stems from the number of volunteers who marked this site. Either way, the probability is never 100%, as in traditional databases. Rather, alternative classifications may be possible. This way, even low-probability sites could be considered, of which many turned out to be actual sites during our following fieldwork (Bourgeois et al., forthcoming). So in this case, ambiguity widens the perspective on a high number of possible sites that enrich and diversify our view of the archaeological landscape of the Veluwe in ways not possible in the traditional binary framework. Clearly, here again, we still need to find good ways of dealing with this ambiguity, which is a great challenge for heritage management and policy (Anttiroiko, 2024). But the benefits of developing new conceptual frameworks that embrace ambiguity are obvious.

Building a career

Even though our field has been around for over half a century, this chair is the first of its kind in the Netherlands. We are lagging behind recent developments across Europe, but only slightly. In Germany, my home country, there are now a

handful of such chairs, plus a number of lecturer positions in Digital and Computational Archaeology, but most of them were established quite recently. The situation is similar across other European countries.

This goes to show that even in a – by now – well-established field, building an academic career can be a challenge. As one of the holders of these rare chairs, I am certainly not complaining. On the contrary, I am immensely grateful for the opportunity, and once again I acknowledge my predecessor, Hans Kamermans, here, whose consistent quality of work over many years, or his stubborn insistence, or both, made the establishment of this chair possible.

Still, in my case, pursuing this career required a lot of personal flexibility and mobility, following job opportunities across three countries and six academic institutions, even with an extended unemployment break in-between that made me seriously question my choices, and finally being offered a full professor position at a much later age than many of my peers in more established disciplines. Today, our field offers more opportunities, but there is still a significant imbalance between the crowds of highly skilled and motivated early career researchers that I meet at conferences in my field and the positions available in higher education and research. If you are in such a position, do not despair! I see two main reasons why building a career today, although still challenging, is much more likely to succeed than a decade or two ago.

The first reason is that digital and computational archaeologists have such a valuable skillset that they can be employed in many fields. Within academia and professional archaeology, their skills come in handy in a broad array of applications and jobs, and the same is true for the wider field of Digital Humanities. Also, their analytical skills, problem-solving attitudes, and technical savviness are in high demand beyond archaeology and academia. It is therefore no surprise that our graduates find jobs in widely different fields, from public administration to finance, and from social care to community service. If you study digital and computational archaeology today, it may be uncertain that you will find a job in archaeology and/or academia, but it is highly likely that you will find a job that corresponds to your skill level. That is certainly encouraging.

The second reason for my confidence is that digital and computational archaeologists today are just *so good* at what they do. I have the privilege of working with a group of brilliant people, who – let us face it – are so much better prepared to meet the challenges outlined above than I could ever be. They have received solid education and training in subjects that I only came across in research contexts after graduation, and they are putting their skills to good use. The PhDs, postdocs, researchers, and lecturers in our group are making actual, meaningful contributions to innovation in our field – more so than I ever could – and it is exciting and humbling at the same time to see them casually excel just doing their day-to-day jobs. Clearly, their future is bright!

So – while building a career in our field can still be experienced as challenging by those who find themselves in such a situation, I am convinced that as a whole, the situation has much improved, and that there is a chance for everyone.

Paying due respect

Academia is always teamwork, so my final challenge is now to pay respect where it is due. In earlier sections, I acknowledged dear colleagues that I have had the honour and pleasure to work with here in Leiden. At earlier career stages, I met people who entrusted me with tasks and responsibilities that helped me develop my profile, and I just want to mention here a few of them: Markus Reindel, Armin Grün, Philippe Della Casa, and Dietmar Saupe – many thanks to you all! Later on, others worked with me on key projects that shaped my career: Igor Zingman, Thomas Reitmaier, Katja Kothieringer, Quentin

Bourgeois, Eva Kaptijn, Suzan Verberne, and Laura van der Knaap – I salute you! There are many other colleagues of similar importance, too many to mention here, and I am beyond grateful for their invaluable contributions to what we celebrate today. The same is true for my students, who are keeping me on my toes – in a good, inspiring way – through their continuous critical evaluation of my work.

Going back even further, I want to thank my parents, who taught me, among countless other things, to treat people with decency and kindness. Even though I do not always follow their example, I have always thought that this basic social skill has contributed as much to my career as all the expertise acquired later.

And finally, I want to thank Lena, my lovely and beloved wife, who joined me on this journey and who gives meaning and joy to all I do. For me, today, this is the most important thing that –

Ik heb gezegd.

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