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Digital Archaeology: Promises and Impasses

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DIGITAL ARCHAEOLOGY

Promises and Impasses

51

ANALECTA
PRAEHISTORICA
LEIDENSIA



edited by
TUNA KALAYCI, KARSTEN LAMBERS
& VICTOR KLINKENBERG

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ANALECTA
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LEIDENSIA

51

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Preface

The present volume started as an idea in 2020 in response to our experience as researchers and lecturers of Digital Archaeology at Leiden University. In this role, we often face the promises of Digital Archaeology, such as technological progress, the data explosion and an increasing demand by students and employers, but also its impasses, such as theoretical unease, practical constraints and doubts about its role in the wider discipline. The emerging Artificial Intelligence (AI) paradigm is exemplary; is the AI paradigm already over-promising, or are we barely unearthing the capabilities of AI-assisted archaeology? It is rather early to have a clear answer to this question, but our collective experience can be telling. In this framework, we tackle a series of digital tools and methodologies in this volume, such as agent-based modelling or archaeogaming. The final list is by no means exhaustive, but we believe it still highlights the astonishing speed of “excitement” and “disappointment” in the scholarship. Our intention was to offer room for critical reflections on these ambiguous aspects that characterize our field, even if only from a biased Leiden perspective. We are grateful to the editorial team of APL for embracing our idea, for dedicating a volume of their book series to it and for offering their support in numerous ways.

This volume would not exist without the enthusiasm of its authors. We are grateful for their inspiring contributions, stimulating discussions and their patience during the overly long editorial process. In our interaction with the authors we were faced with exciting articles about topics that had not occurred to us, but also with articles that sadly could not be realized for various reasons. In this sense the editorial process mirrored the promises and impasses that this volume is about.

We also want to thank the many reviewers who provided critical and insightful feedback, the language editors who prevented a number of Dutchism and other isms from slipping through, and the editorial staff at Sidestone Press who turned our manuscript into a beautiful book. It is our hope that the combined efforts of all these people will result in an inspiring read.

Tuna Kalaycı
Karsten Lambers
Victor Klinkenberg

Introduction: Leiden Perspectives on Digital Archaeology

Karsten Lambers

1 DIGITAL ARCHAEOLOGY

What is 'digital archaeology'? As lecturers of digital archaeology at Leiden University, we should probably be able to provide a succinct definition. Yet it is a notoriously broad, vague and ambiguous concept, something archaeologists seem to be so fond of – think of often used concepts such as 'culture', 'interaction' or 'landscape' that are hard to define yet undoubtedly productive.¹ In the case of digital archaeology, both the concept and the term have been a matter of considerable debate (Huggett 2013, Tanasi 2020).

On the one hand, 'digital archaeology' seems redundant, as today all archaeology is digital to some degree. Even the most basic fieldwork is usually undertaken with the assistance of digital technology, *e.g.*, in the form of surveying devices, spreadsheets or photographs. In this sense there is no doubt that 'we are *all* digital archaeologists' (Morgan and Eve 2012, 523; emphasis in original). Speaking of photography, it is a good example of how quickly perceptions can change when innovation becomes mainstream. What used to be called 'digital photography' when it was introduced more than two decades ago is now simply known as 'photography'. Is the same happening with digital archaeology?

Apparently not, because, on the other hand, digital archaeology is an expanding field (Tanasi 2020). Numbers of students and faculty positions are on the rise, conferences and publications on the subject abound, and there is an active international community of researchers and practitioners of digital archaeology. Clearly, 'digital archaeology' is an attractive concept that holds many promises for those who engage in it – including students who choose it as their specialization, as we will see later on.

Yet, these promises are not always fulfilled. Over the past decades, digital archaeology has embraced many emerging digital technologies and methods in the hope of making archaeological research into the human past easier, quicker or better in a number of ways, *e.g.*, by making it more efficient, thorough, robust, comprehensive, transparent, quantifiable, reproducible, open, inclusive, or many other things. Often, the uptake of such technologies and methods goes through a hype cycle in which, after an initial trigger, a 'peak of inflated expectations' is followed by a 'trough of disillusionment' before hopefully ascending a 'slope of enlightenment' to reach a 'plateau of productivity' (Fenn and Raskino 2008). In archaeology, probably the most prominent digital technology that has gone

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1 None of these common concepts is defined in *Archaeology – The Key Concepts* (Renfrew and Bahn 2005), although some of them are referred to under other headings.

through such a cycle is GIS. After an initial hype in the 1980/90s, some rather shallow early GIS applications were rightfully questioned before much more solid, theoretically well-founded and genuinely archaeological approaches to spatial analysis and data management in GIS were developed that today are part and parcel of the archaeologist's toolbox (Howey and Brouwer Burg 2017; Verhagen 2018).

Despite its ups and downs, the history of archaeological GIS applications is probably a best-case scenario. Many other digital technologies and methods in archaeology have not yet reached the plateau of productivity, with varying prospects if they ever will, and a few of them are discussed in this volume. So apart from promises, digital archaeology is also full of (potential) impasses.

2 PROMISES AND IMPASSES

This is why we chose the topic of this edited volume. 'Digital Archaeology: Promises and Impasses' brings together essays that reflect on the use of digital technologies and methods in archaeological research and heritage management as practical tools and as heuristic and epistemological devices. It offers a range of insights into a somewhat underrated aspect of those approaches, namely their unfulfilled promises, underachievements and limitations. We feel that such aspects are important for critical, responsible and appropriate use and the further enhancement of digital technologies and methods. Although we have no data to back this up, our impression is that publications in our field – as in other fields – tend to be skewed towards positive results and success stories, of which undoubtedly there are many. So our own *Analecta Praehistorica Leidensia* (APL) series offers a welcome opportunity to give room to more critical perspectives and reflections.

Following the tradition of edited volumes in the APL series, we invited current and former members of the scientific staff of the Faculty of Archaeology of Leiden University to contribute perspectives from their own research. Many of them followed our internal call in spite of their numerous other commitments, and some of them invited external colleagues as co-authors. All papers were peer-reviewed by external experts. We are immensely grateful for the commitment of all these authors and reviewers. Other colleagues were unable to contribute to this volume at the time of the call for perfectly good reasons, *e.g.*, because they had to defend their Ph.D. theses in digital archaeology (Brandse 2022; Verschoof-van der Vaart 2022). Due to these constraints, this volume cannot claim to

represent the full breadth and depth of research in digital archaeology at our faculty, nor much less so beyond. Still, we hope that it offers valuable insights.

In order to put the contributions from our faculty in a broader perspective, we invited Rachel Opitz to reflect on them in a concluding chapter, and we are extremely grateful that she accepted. Her impressive track record in research in digital archaeology, her long-standing experience as Senior Lecturer in Spatial Archaeology at the University of Glasgow and her former function as chair of the Scientific Committee of CAA (Computer Applications and Quantitative Methods in Archaeology) put her in a unique position to contextualize and discuss the contributions by our authors.

3 THIS VOLUME

The following chapters describe uses of digital technologies and methods at different steps of the workflow of archaeological research, ranging from data collection in the field to data processing and analysis, and to archiving, re-use and dissemination. All the digital approaches discussed are clearly past their initial hype or did not live up to the high expectations with which they were initially received. Often, further testing, development, standardization, and/or critical reflection are required before a given approach can be broadly applied in a productive and meaningful way. To which degree this will happen is not always clear, but in their insightful discussions, the authors attempt to point out ways to move forward.

Across the following chapters, the authors offer a range of different perspectives on the topic of the volume, *i.e.*, on promises and impasses of digital archaeology. Some of them discuss practical, methodological, or philosophical implications of the use of digital technologies and methods in archaeological research, and many of their insights apply beyond the specific approach that they discuss. Others are concerned with the archaeological community's limited uptake of promising methods and possible reasons for it. A recurring theme is obstacles or constraints encountered in the application of digital approaches. These can be technical, financial or regulatory in nature, but often they are rather related to limited education or training on the part of the (intended) users. Clearly, digital skills and computational literacy are not yet as pervasive in the archaeological community as many digital archaeologists may think or wish, and this is perhaps one of the main reasons why promises of digital archaeology remain unfulfilled or are even misguided. From a different perspective, this finding is confirmed by our students at Leiden University.

4 STUDENTS' PERSPECTIVES

In keeping with the editorial policy stated above, our internal call was directed at research and teaching staff at our faculty, but we value our students' perspectives on digital archaeology just as much. As future practitioners, they will be responsible for how digital archaeology is shaped in the future. Therefore, we use the opportunity offered by this introductory chapter to review the perspectives of Leiden students of (digital) archaeology based on empirical and anecdotal data. Doing so, we are aware that these perspectives are not necessarily shared by (digital) archaeology students elsewhere.

Thanks to the pioneering efforts of Hans Kamermans and later, Milco Wansleeben and others, digital archaeology – though originally not under that label – has been deeply engrained in our education programmes since the mid-1980s (Kamermans 1987). Today, starting at the undergraduate level, each year the new BA students (2022: >120) take compulsory courses in 'Exploratory Data Analysis' (first year) and 'GIS' (second year). This is complemented by optional specialization courses in the second and third years (e.g., on Predictive Modelling or Programming).

On the graduate level, in 2016 Digital Archaeology was added as the fifth specialization track to the MSc programme 'Archaeological Science', the other four tracks being Material Culture Studies, Osteoarchaeology, Archaeobotany and Archaeozoology. Within this programme, the digital archaeology track quickly gained popularity and has produced 23 MSc graduates so far (as of summer 2022), among them 15 international students. In addition, more than a dozen MSc students are currently working on their theses in digital archaeology.

These students and graduates provide fresh views on digital archaeology that are rather shaped by personal perspectives than by the ongoing academic debate. Reviewing their applications, talking to them in class and discussing their choices of thesis topics gives us valuable insights into their motivations and expectations, which we try to summarize in the following. Many (international) students found our MSc programme by specifically searching for the term 'digital archaeology' on the internet. A clear and easy-to-understand label is thus important for the visibility of our programme. The abovementioned debate about the concept and the term notwithstanding, 'digital archaeology' is a strong brand that enables us to reach our target group.

Two reasons for choosing digital archaeology clearly stand out from our students' feedback: 1) 'It is the future of archaeology' and 2) 'It will help me find a job'.

Optimistic as they are, both statements nicely reflect the promises that digital archaeology holds, the first one regarding the academic discipline as a whole, the second one the personal prospects of its practitioners. From a student's perspective, is there any indication that digital archaeology can keep its promises?

4.1 Students' career prospects

Starting with the prospects on the labour market, we know from around a dozen of our digital archaeology MSc graduates what kind of jobs they found afterwards. About half of them remained in archaeology, some of them pursuing a Ph.D., others working as researchers or managers for academic institutions or heritage agencies. The other half started jobs outside of archaeology in a diversity of fields, ranging from community services to surveying and from data analytics to finance. In spite of this variety, a common feature is that many graduates cite skills acquired during their digital archaeology studies as instrumental in finding their jobs, especially Information and Communication Technology (ICT) skills such as data management, GIS, modelling, or coding. GIS skills in particular seem to be a valuable asset in the labour market well beyond archaeology.

The importance of ICT skills was also an aspect of polls among archaeology graduates in the Netherlands about their job situation that we cite here for context. Femke Tomas, archaeologist and education officer at Saxion University of Applied Science (Deventer) is currently analysing data from two surveys among Leiden and Saxion graduates for her Ph.D. research about labour market perspectives of archaeology students. She kindly agreed to share some partial results here.

The Leiden survey covered graduates from all our archaeology programmes (BA to Ph.D. level) between 2008 and 2018, while the more recent Saxion survey covered graduates from their only archaeology programme (BSc) between 2011 and 2021 (table 1). While the two polls differed in terms of target group, design and scope, both tried to determine, among other aspects, the importance of ICT skills for archaeology graduates. Note that this covers *all* archaeology graduates, whether they specialized in digital archaeology or not.

Of the 657 employed Leiden graduates, 73 or 11.1% worked in ICT-related jobs, 0.6% within archaeology and 10.5% elsewhere. So within archaeology, at the time of the poll, the importance of ICT skills seems limited, although they may play a secondary role in

| a) Leiden Archaeology Graduates (BA-MA/MSc-RMA/RMSc-Ph.D.), 2008-2018 | | | | | b) Saxion Archaeology Graduates (BSc), 2011-2021 | | | | |
|---|------------|-----------|---------------|--------------|---|------------|-----------|---------------|--------------|
| Number of alumni: 955, out of which employed: 657 | | | | | Number of alumni: 222, out of which employed: 164 | | | | |
| Field | Number | in ICT | Percentage | in ICT | Field | Number | in ICT | Percentage | in ICT |
| Academia | 185 | | 28.2% | | Archaeology | 84 | 4 | 51.2% | 2.4% |
| Archaeology | 209 | 4 | 31.8% | 0.6% | Related | 40 | 19 | 24.4% | 11.6% |
| Other | 263 | 69 | 40.0% | 10.5% | Non-related | 40 | 8 | 24.4% | 4.9% |
| Total | 657 | 73 | 100.0% | 11.1% | Total | 164 | 31 | 100.0% | 18.9% |

Table 1: Partial results from polls among a) graduates from Leiden University archaeology programmes, 2008-2018, n=657 (employed), and b) graduates from Saxion University of Applied Science archaeology programme, 2011-2021, n=164 (employed). While employing different categories, both polls aimed at determining the job situation of former archaeology students of either institution after graduation and the role of ICT skills. Data courtesy of Femke Tomas, Saxion University of Applied Science, Deventer.

non-ICT jobs as well. Beyond archaeology, ICT skills are more important, accounting for a quarter of the jobs.

A few years later, of the 164 employed Saxion BSc graduates, 31 or 18.9% worked in ICT jobs, more than half of them (14.0%) in archaeology or related fields. This seems to indicate the growing importance of ICT skills within archaeology.

Seeing these numbers in conjunction with the anecdotal feedback from recent Leiden digital archaeology graduates cited above, it seems clear that ICT skills acquired in archaeology programmes are today a valuable asset in the labour market. While not a decisive factor, their importance has grown over time. However, many (digital) archaeology graduates find jobs outside of archaeology, often intentionally due to better working conditions in other sectors (Femke Tomas, pers. comm. 2022). So, while the expectation of finding a job is met, those jobs are not necessarily in archaeology.

4.2 Students' thesis topics

Another line of evidence is provided by the thesis topics that our digital archaeology students choose. MSc theses in digital archaeology usually have a methodological focus. As per the requirements of our MSc programme, the students develop their thesis topics themselves based on their own interests and skills, within the framework of our regulations but otherwise only constrained by the availability of data and tools. While the areas of our own expertise, which certainly do not cover the entire field of digital archaeology, might be considered another constraint, we have so far been able to accommodate almost all thesis topics proposed by our students. These topics can thus serve as an indication of the student's preferences.

Until the time of writing in the summer of 2022, 23 theses in digital archaeology were completed at least to the level of a full draft. On average, four theses were completed each year, with a dip in 2021 due to the Covid-19 pandemic compensated for in 2022. The thesis topics can be broadly categorized into six sub-fields of digital archaeology (figure 1), with most theses spanning multiple sub-fields. Although once again the sample is small, certain trends are evident.

With slight variations, four sub-fields of digital archaeology are more or less constantly present among the students' choices. These include GIS / Spatial Analysis, 3D Modelling / Virtual Reality, Remote Sensing / Image Analysis, and Data Management / Open Science. Most people would probably agree that these sub-fields have formed the stable core of digital archaeology over the past decades, perhaps with noteworthy recent additions such as the growing importance of Open Science or the convergence of the first two topics in 3D GIS. In this sense, our students' choices seem to be in line with the mainstream of our field. This may also be true for minor shifts over time, such as recently a slight decrease in GIS / Spatial Analysis and 3D Modelling / Virtual Reality and a slight increase in Remote Sensing / Image Analysis and Data Management / Open Science.

While it remains to be seen if these subtle trends stabilize, two other sub-fields of digital archaeology have clearly gained popularity in recent years, namely Agent-based Modelling and Machine Learning. This trend is noteworthy as these sub-fields are more narrowly defined in methodological terms than the other four, although their range of applications is at least as broad. Thesis research in these sub-fields is also more ambitious in the sense that students usually have

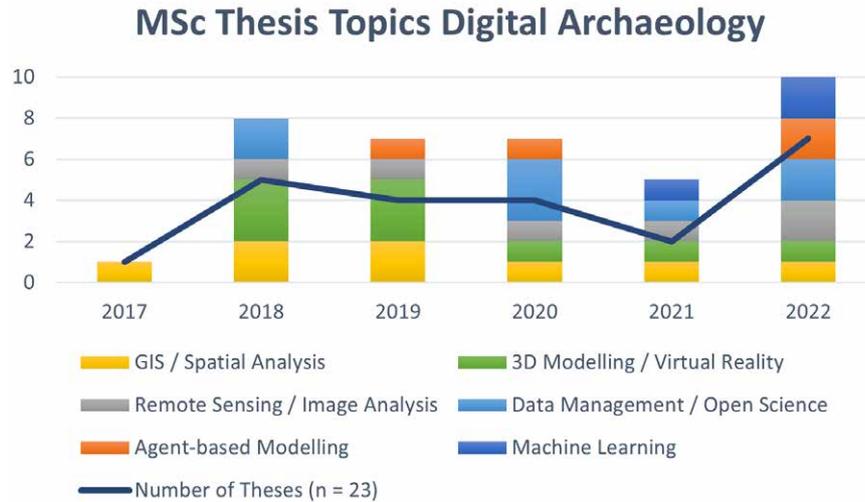


Figure 1: Sub-fields of digital archaeology that best capture the methodological focus chosen by students of the Digital Archaeology track of the MSc programme Archaeological Science at the Faculty of Archaeology, Leiden University, from 2017 to 2022. Number of theses: 23. Multiple sub-fields per thesis possible and common. All theses available in Leiden University's Student Repository at <https://studenttheses.universiteitleiden.nl/>. Graph: K. Lambers.

no prior skills (*e.g.*, modelling, coding) when entering our MSc programme, contrary to the abovementioned four sub-fields of which some basic concepts are usually taught at the undergraduate level. It seems that more and more students deem the required learning effort worthwhile and are willing to take on this challenge. This indicates that our students have a keen sense of the opportunities afforded by these advanced fields.

Absent from this overview are two further sub-fields of digital archaeology, though for different reasons. One of them is Quantitative Data Analysis / Statistics. Rather than a real absence, this is a classification problem, as virtually all theses in digital archaeology include quantitative data analysis at varying degrees, some more explorative, others more analytical. Yet few theses focus on these methods, which is why they did not receive their own category here. In fact, the use of quantitative and statistical methods is a common feature of all theses across the five tracks of our MSc programme in Archaeological Science.

The other absent sub-field of digital archaeology is Archaeogaming. While there are no completed MSc theses in this sub-field yet, it is safe to assume that this will change soon, considering how Archaeogaming recently gained popularity among our students.² Many

of our students are active or even passionate gamers and as such are quick to grasp the potential of games for simulating the past in an interactive, immersive and fun way and for engaging audiences that might be difficult to reach through more traditional channels.

4.3 Students' essays

The choice of the thesis topic is relevant for the second of the abovementioned promises of digital archaeology, namely the prospects of our students in the labour market after graduation. The overview so far may seem to indicate that our students are purely skill and job oriented. But in fact, their main motivation to choose digital archaeology is rather related to the first promise mentioned above, namely that it is the future of archaeology. Beyond their personal situation, students are very much interested in current trends within our field, but also beyond, trends in academia and in society at large.

A valuable source for students' interest in these matters are the final assignments of our digital archaeology specialization course in the MSc programme. In this course, offered once each academic year, we discuss the nature and future of digital archaeology with the students and ask them to write an essay about this topic. There are two reasons for doing so. One is the ongoing scholarly debate about digital archaeology (see above), of which our graduate students should be aware and on which they should reflect. The other reason is that their opinions on this topic matter.

² Not the least thanks to the activities of the Leiden-based VALUE Foundation (<https://value-foundation.org/>).

The students choose digital archaeology for a reason, and many of them even come to Leiden from abroad for doing so. So their perspectives can shed light on what digital archaeology is or potentially can be.

From these essays, it becomes clear that the students are keenly aware of current trends in our field.³ The most pervasive of them is digitalization, something that students experience not just in archaeology but in their daily lives. As digital natives, they do not question this trend but regard it as a given. That is an important difference for many digital immigrants, ourselves included (Visser *et al.* 2016). The students experience what digitalization means for the way we inquire about the human past (see *e.g.*, archaeogaming, above). In their courses, internships and thesis research they experience the huge potential of digital data, tools and methods, but just as often they face constraints such as those things not being openly available. Among our students, restricted access is widely regarded as a detrimental and outdated concept that should be overcome, the sooner the better. Most students embrace and support the principles of open science fervently, perhaps more so than some of their teachers.

In this context, students are quite aware of the data deluge that archaeology is facing (Bevan 2015), maybe more so in the archaeological sciences that (re-)use lots of digital data from the environmental sciences than in other fields of archaeology. While digital archaeology students are willing to take on this challenge, they feel that archaeology as a discipline is inadequately equipped and prepared for doing so. Consequently, they expect and demand more formal education and training in data management, data science and general computational literacy. They do not want to lag behind the trend but get ahead of it in order to give it shape and direction. In this sense, they want to be much more than technicians, in line with Llobera's (2011) vision.

At the same time, the students are aware of the ethical challenges that digital archaeology faces or even causes. The 'digital divide' is not just an abstract concept for them, but something they experience first-hand, *e.g.*, when doing digitally assisted archaeological fieldwork in different sociocultural environments. This

makes many students reflect on for instance power hierarchies, inclusiveness or the need to decolonize archaeological practice, and they seek meaningful ways to address these topics in their own research and practice. But there are also ethical challenges posed by the nature of certain digital technologies, *e.g.*, the lack of transparency of how certain data or results are generated, as exemplified by general-purpose LiDAR data or the black box problem of deep learning. Here again, students understand the problem and are willing to take on the challenge, but expect to be better prepared, educated and trained.

All in all, we see a lot of clarity, sincerity and foresight in the way our students view digital archaeology and its role in the wider discipline. It is thus perhaps unsurprising that few of them are appreciative of the academic 'anxiety discourse' as diagnosed by Huggett (2013), which they tend to consider as detached, unproductive and moot (and they are not shy of saying so in their essays). They are generally more interested in what they consider practical solutions to problems that they experience. In this sense, they firmly believe that digital archaeology can keep its promises, provided more is done to facilitate this, especially through education and training.

5 CONCLUDING / OPENING REMARKS

The present volume reviews promises and impasses of digital archaeology based on research and teaching experience at our faculty. As such, it is a small and biased contribution to the ongoing debate about digital scholarship in archaeology (*e.g.*, Huggett *et al.* 2018). The following chapters provide insights into the limitations of certain digital technologies and methods, but also productive and reflective ways of dealing with them. In this sense, we hope that they also help to better understand where these approaches stand in the hype cycle, if at all.

Zooming out from specific problems, it is clear that digital archaeology is still an attractive field that holds many promises for those who engage in it. The following chapters written by current practitioners, but even more so the perspectives of future practitioners cited above showcase what is required to keep those promises and to avoid impasses. The current generation of students demands loud and clear that we step up our game of education and training in digital skills and computational literacy, not just to enhance their career perspectives but also to future-proof archaeology.

We invite our readers to keep this challenge in mind when enjoying the following chapters.

3 Due to regulatory reasons, it is not possible to cite those written assignments here. Which is unfortunate, as they are inspiring and rewarding to read, and the students' valuable contributions to this chapter through their essays and other feedback are gratefully acknowledged.

REFERENCES

- Bevan, A. 2015. “The data deluge”, *Antiquity* 89: 1473-1484. DOI:10.15184/aqy.2015.102.
- Brandesen, A. 2022. “Digging in documents: using text mining to access the hidden knowledge in Dutch archaeological excavation reports” PhD diss., Leiden University. <https://hdl.handle.net/1887/3274287>.
- Fenn, J., and M. Raskino. 2008. *Mastering the hype cycle: how to choose the right innovation at the right time*. Boston: Harvard Business Review Press.
- Howey, M.C.L., and M. Brouwer Burg. 2017. “Assessing the state of archaeological GIS research: unbinding analyses of past landscapes.” *Journal of Archaeological Science* 84: 1-9. DOI: 10.1016/j.jas.2017.05.002.
- Huggett, J. 2013. “Disciplinary issues: challenging the research and practice of computer applications in archaeology.” In *Archaeology in the digital era. Papers from the 40th Annual Conference on Computer Applications and Quantitative Methods in Archaeology (CAA), Southampton, 26-29 March 2012*, edited by G. Earl, T. Sly, A. Chrysanthi, P. Murrieta-Flores, C. Papadopoulos, I. Romanowska and D. Wheatley, 13-24. Amsterdam: Amsterdam University Press. DOI:10.1515/9789048519590-002.
- Huggett, J., P. Reilly, and G. Lock. 2018. “Wither digital archaeological knowledge? The challenge of unstable futures.” *Journal of Computer Applications in Archaeology* 1: 42-54. DOI:10.5334/jcaa.7.
- Kamermans, H. 1987. “Computergebruik in archeologie.” *Fibula* 28 (4): 24-28. <https://hdl.handle.net/1887/17605>.
- Llobera, M. 2011. “Archaeological visualization: towards an Archaeological Information Science (AISc).” *Journal of Archaeological Method and Theory* 18: 193-223. DOI:10.1007/s10816-010-9098-4.
- Morgan, C. and S. Eve. 2012. “DIY and digital archaeology: what are you doing to participate?” *World Archaeology* 44: 521-537. DOI: 10.1080/00438243.2012.741810.
- Renfrew, C. and P. Bahn. 2005. *Archaeology: the key concepts*, London, New York: Routledge
- Tanasi, D. 2020. “The digital (within) archaeology. Analysis of a phenomenon.” *The Historian* 82: 22-36. DOI:10.1080/00182370.2020.1723968.
- Verhagen, P. 2018. “Spatial analysis in archaeology: moving into new territories.” In *Digital geoarchaeology: new techniques for interdisciplinary human-environmental research*, edited by C. Siart, M. Forbriger and O. Bubenzer, 11-25. Springer. DOI:10.1007/978-3-319-25316-9_2.
- Verschoof-van der Vaart, W.B. 2022. “Learning to look at LiDAR: combining CNN-based object detection and GIS for archaeological prospection in remotely-sensed data” PhD diss., Leiden University. <https://hdl.handle.net/1887/3256824>.
- Visser, R., W. van Zijverden, and P. Alders. 2016. “Teaching digital archaeology digitally.” In *CAA 2015 Keep the revolution going: proceedings of the 43rd annual conference on Computer Applications and Quantitative Methods in Archaeology*, edited by S. Campana, R. Scopigno, G. Carpentiero and M. Cirillo, 11-15. Oxford: Archaeopress.

Metaphors, Myths, and Transformations in Digital Archaeology

Tuna Kalaycı and Piraye Hacıgüzeller

1 INTRODUCTION

"We are *all* digital archaeologists" (Morgan and Eve 2012, 523, emphasis in original). The digitalization of archaeological practice has indeed been more visible in recent years¹. Even on a day with little computation needs, we work on a variety of scholarly tasks. Typing in a word processor, sharing files in the cloud, browsing an online atlas, sending e-mails, and teaching on platforms are only to name a few.

Yet, as early as the 50's, Gardin was asking, "[c]an one resolve-or partially resolve [...] difficulties by the construction of standard categories that are relatively culture-free and by the use of mechanical aids such as systems of punch-card indices?" (1958, 335). This is the age-old categorisation problem, though we are (seemingly) less coerced by the 'culture-free' -ness doctrine. In 1962, "the use of computers in anthropology" symposium was organized (Hymes 1963). In 1973, the first conference on Computer Applications in Archaeology (CAA) brought together the pioneers. By the 1980s, colleagues were already experimenting with the first modern remote sensor technologies (Custer *et al.* 1986). The Center for the Study of Architecture published the CSA Newsletter on early digital technologies in 1988... moving fast-forward to the current day; one can access high-performance computing (HPC) over the internet, a power probably unimaginable to achieve not so long ago. We admittedly provide a simple-linear historical narrative hereby. However, a more detailed and inclusive history would have probably still pointed at early digital archaeologists -less visible and fewer in number than today; in the 21st century we are finally all digital (Morgan and Eve 2012).

As we make digital transformations, current computational advancements are increasingly promising that we can -once again- *push the envelope* using *cutting-edge* tools and technologies and move *beyond state of the art*. The most recent innovation, Artificial Intelligence (AI), is now famously called "the new

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1 We acknowledge that computation is a new signifier as analogue computation has been known to the archaeologist for some time (*e.g.*, Antikythera mechanism – 2nd century BC, or al-Jazari's classic automatons – 12th century CE). Computers predate the digital, and can be even biological. Women were called "computers" (Light 1999), setting the stage for modern-day routines and algorithms as they laboriously performed computation by hand. As we cruise our way in the complex socio-technical history, we use the terms computation and digital interchangeably. Overall, we consider "digital archaeology" an umbrella term that encompasses everyday-life activities. To us, "computational archaeology" suggests codes, simulations, GIS models, machine learning, or many similar techniques, which require more training and experimentation with digital computers.

electricity” (Lynch 2017). AI changes the way people compute; it is a move away from theory building and modelling and is a step towards a data-driven reading of the world. While the current artificial intelligence boom is everywhere, from law to medicine and from archaeology to astronomy, the innovation² has been making periodic appearances in the academic landscape since the 1970s. Each burst was followed by an AI winter (Floridi 2020). What is probably new is the AI-based prediction and classification of everyday life. So, there are already voices that call for algorithmic silence and to decomputerize (Penn 2021). These voices demand special attention, especially since they are accompanied by influential statements as: “[w]e thought knowledge was about finding the order hidden in the chaos. We thought it was about simplifying the world. It looks like we were wrong. Knowing the world may require giving up on understanding it” (Weinberger 2017); it is a statement that is at odds with our scientific practice (Mazzocchi 2015).

We hope that true digitalization facilitates mutual interaction between the agents of knowledge. Many would probably agree that digital co-creation is promising (Giaccardi 2012; Simon 2011). Digital can potentially empower people to explore and understand their past. Moreover, cheaper computation promises to reach broader audiences. In the meantime, *free* applications and online platforms (e.g., Google Earth) facilitate and organize work. The promise accompanies a growing optimism in technological advancements and faith in absolute digital futures/twins. However, we are also aware that our digital relationships and relationships with the digital are ever-complex and growing in time. And as the digital world grows, we collectively produce and witness broken promises.

There is tremendous value in and through digital, and as “digital archaeologists” we welcome the progressive digitalization of our archaeological discipline. However, as the authors, we also observe that a digital promise may not always satisfy to the expectations of the digital practitioner. We explore this condition through a critical reading of digital metaphors and myths. We suggest that through these two concepts, we can *also* understand how and why

(false) promises and (avoidable) impasses are brought about. Specifically, in the following we also try to understand how digital influences/transforms our understanding of archaeological collaboration and labour. We suggest studying metaphors, myths, and transformations might offer some hints for tackling *failed promises*. We aim to situate ourselves in a sandbox (Politopoulos and Mol, this volume) where we build and unbuild things. Yet, our aim is not to offer an alternative framework to digital archaeology but highlight some of the influential agencies related to the production of archaeological knowledge.

2 (DIGITAL) METAPHORS AND MYTHS

Forming, using, and forgetting metaphors and myths are fundamental human traits. Metaphors help us understand one concept through understanding another (Lakoff and Johnson 2008; Massey and Ehrensberger-Dow 2017). And, simply put, a myth is a network of ideas without necessarily imposing truth or falseness (Christensen and Cornelissen 2015). As they explain much about us, metaphors and myths are subject to countless inquiries through scholarly work.

The metaphor has more visibility in linguistics, but as archaeologists, we can still focus on the metaphorical instead of the semiotic nature of material culture (Coward and Gamble 2010, 48). Metaphors also shape epistemologies. One of the richest examples of a metaphor is the map (Smith 2007). At the end of the day, “[s]pace is fundamental in any exercise of power” (Foucault 1984, 252), and maps facilitate authorship. Metaphors also help archaeologists transfer ideas from other disciplines, as in “the use of the evolutionary metaphor” (Bamforth 2002, 435). Archaeology can be a metaphor itself: “[i]n face of the incompleteness of my analytic results, I had no choice but to follow the example of those discoverers whose good fortune it is to bring to the light of day after their long burial the priceless though mutilated relics of antiquity... like a conscientious archaeologist, I have not omitted to mention in each case where the authentic parts end and my constructions begin.” Freud (1953, 12). Metaphor shapes the digital world. The user commands the flow of electronic signals on the *desktop*. Our desktop has *files, notepads, folders, recycle bins, etc.* Metaphors are also part of internet terminology; *web, portal, and gateway* are only a few.

We now move on to the myths. In and through archaeology, we may make myths more visible or challenge them by, for instance, exploring Indo-European origins (Mallory 1992), revealing

2 For a critique of the term, see Edgerton (2011). For instance, he asks why we consider 21st-century electric cars innovative if around 20% of motor taxis were already electric between 1907 and 1918 (2007: 9).

uniformized pasts (Olsen 1986), scrutinizing existing narratives (Hall 1984), or disentangling the state's role in these narratives (Fowler 1987). The list is long, so we fast-forward again and point at the resurgence of older myths in the new scientific era. Ancient DNA analysis, a promising tool, is now also a myth-maker (Hakenbeck 2019; Wolinsky 2019) and it now influences the narratives of politicians (Hamilakis 2017; Netanyahu 2019) and the public (Broodman 2017).

Not surprisingly, myths are also part of the digital world. We claim through myths and myth-making the digital finds place in our lives. Realizing how digital myths are shaping the world many colleagues have been studying many aspects of the phenomenon in different scholarly, socio-economic and geographic contexts and helping us to build informed digital futures (*e.g.*, Alzouma 2005; de Saint Lauren 2018; Jennings and Zeitner 2003; Kirschner and De Bruyckere; Webster 2017; Ziewitz 2016).

The digital usually arrives with a narrative suggestive of particular understandings and readings of the world. So, we hope to challenge some fundamental assumptions we make about the digital archaeology as well. To start our inquiry, we first explore two examples (the cloud metaphor and the myth of digital inclusivity) in their general and archaeological contexts. We consider archaeology broadly, including research, education, field practice, museum studies, heritage and the like. We selected these examples opportunistically and based on our interests. It should be possible to identify and explore other examples.

2.1 The Cloud Metaphor

Cloud computation involves distributing digital tasks over (a network of) large data centres equipped with high-processing computers. Mainly determined by the infrastructure needs, a cloud can be as large as a warehouse. Users connect to the cloud and perform online tasks, ranging from scientific computation to email communication. Depending on the amount and frequency of demand by users, computation resources can be scaled up and down, “creating the illusion of infinite resources available at any time” (González-Martínez *et al.* 2015, 132). Motivated at least by the idea of infinite computation, clouds promise access to digital platforms, software, and data storage space at lower costs. After all, the invisible hand of competition benefits all (see Zernik 2019).

Khmelevsky and Voytenko (2010, 1) identify three major trends in cloud computing:

- Virtualization (the separation of apps/software from hardware)
- Utility computing (metered use of hardware)
- Software provisioning (on-demand use of software)

Aligned with these trends, we are gradually moving away from high-performing personal computers and local servers for our scientific needs; it is now possible to command a virtual machine and perform complex tasks in the cloud using a rudimentary computational device with a reliable internet connection. In particular, technologists, scientists and policymakers are expecting 5G will bring massive changes to cloud computing as experts claim ultra-fast data transmission will -once again- revolutionize³ network and communication technologies.

Cloud experts almost always communicate with the rest through graphical representations of the metaphor. To the common eye, data icons, app symbols, digital services and other Internet of Things (IoT) objects surround the cloud (figure 1). These representations imply cloud computing is flexible and always open to changes. Therefore, the metaphor carries the image of scalability but sustains a sense of distance; it is beyond one's reach. The digital metaphor starts obscuring the material even at this very representation stage. We are interested in this metaphorization for two main archaeological reasons. First, we want to understand the digital entity (*e.g.*, a row in a spreadsheet, an e-mail, a 3D scan of an object, a pre-trained deep learning model, etc.) as a sociotechnical object and explore the producers of its possibility, such as “infrastructures, assemblages, and political economies” (Philip *et al.* 2012, 10). Second, we want to highlight the materiality of clouds and opportunistically plot archaeologists' interaction with the cloud so that the cloud is closer to reach.

It is simply because cloud computation relies on physical infrastructure. Consequently, the cloud is an infrastructure. It is made of advanced computing

3 <https://www.ibm.com/industries/telecom-media-entertainment/resources/5g-revolution/>
The frequency of these revolutions is astonishing -to our reading their pace exceeds and dilutes the meaning of the word. In scientific framework, for instance, the discovery of penicillin was revolutionary as it shifted the perception of death in human societies. It is not clear how and why the 5G revolution is different from the 4G revolution.

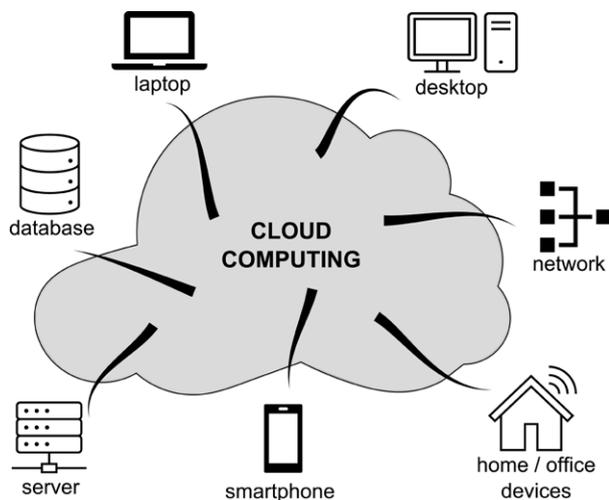


Figure 1: A common graphical depiction of cloud computing. The concepts/icons surrounding the cloud may change in number or arrangement, but the computing is clouded.

machines stacked side by side and on top of each other, sometimes kilometres-long fibre-optic cables, a reliable electricity grid, cooling machinery, and a strong building (even former World War bunkers and military-grade underground facilities⁴) to house everything. The cloud is the name of a physical meshwork, junctions being the data centres. Through the material visibility of a warehouse, “cloudinfrastructures alert us to multiple layers of carefully produced and guarded invisibilities” (Furlong 2021, 191). And, in the invisibilities, we attempt to highlight power structures/agencies embedded in infrastructures and their building processes (Rodgers and O’Neill 2012), but mainly in the context of archaeology and heritage studies.

To begin with, working in the cloud gives a sense of decentralization. However, cloud computing does not exhibit signs of deterritorialization on actual geography. Rather, it presents a model of reterritorialization (Amoore 2018, 8). Large data centres mainly owned by the big-tech companies cluster in geographies that provide access to energy, tax incentives, water sources, and suitable digital infrastructure. The infrastructure sits in certain locations since stable data flow also requires stable political geographies. The recent plea for energy efficiency and carbon footprint reductions also

influenced tech companies to locate their warehouses in countries with a tradition of building green energy infrastructures, such as Denmark (Maguire and Ross Winthereik 2021) while making use of colder climates. These high-performing cloud machines require periodic upgrades to keep up with the number and amplitude of digital requests, at the cost of giving a sense of infinite resources. So, electronic waste is building up (Lepawsky 2015). It is no surprise then that the centralization of computing is a geo-political process (Roguski 2020).

2.2 Cloud Computing in Higher Education and Archaeological Research

The cloud paradigm/metaphor is consequential all across the board, including education and research. For instance, open-source software has a conflicted relationship with the cloud (CYOP *n.d.*; Ramel 2021; Tunguz 2021). It is not certain how cloud computing will merge with the open-source / open-access paradigm. Archaeology, being a “financially-poor” discipline, widely benefited from the open source. On a broader scale, archaeologists have been making significant progress in open science, notably in digital data. While significant experience is being accumulated, it is still unknown how platformization and cloud computing will affect the future of collaborative archaeological knowledge production.

To begin with, archaeologists use the cloud in various ways, such as performance computing (*e.g.*, Rubio-Campillo 2015) or fieldwork (*e.g.*, Matsui *et al.* 2012). Heritage studies in general, but museums in particular, are leading the path in cloud-based solutions (*e.g.*, Vecchio *et al.* 2015; Yang *et al.* 2020). Constructing digital 3D objects and performing photogrammetric solutions in the cloud are notable examples of the new computing paradigm (*e.g.*, Kersten and Lindstaedt 2012). Public engagement can also happen in the cloud (*e.g.*, Lambers *et al.* 2019). Citizen science projects, such as Zooniverse, are built over a cloud platform, in this instance, Microsoft’s Azurecloud computing service.

Museums are of particular interest. Digitalization of material culture and generation of massive amounts of data now requires high-tech solutions; big data requirements are pushing the operational capabilities of institutions (Pesce *et al.* 2019, 1884). To satisfy digital needs, museums should either improve their infrastructures through machinery purchases and technical staff hires, or collaborate with new partners. With their scalable cloudinfrastructures, big tech offers

4 <https://datacentremagazine.com/data-centres/top-10-underground-data-centres>.

services and solutions -museums as the content creators. In collaboration with Google, some prominent museums (e.g., Musée d'Orsay in Paris, British Museum in London, Rijksmuseum in Amsterdam, and Acropolis Museum in Athens) have set up online interactive museum visits and object interaction displays thanks to cloud technologies.

Universities and research institutes also use cloud solutions by the big-tech (Khmelevsky and Voytenko 2010; Al-Busaidi 2012). Higher education profits from cloud computing at different levels. For instance, now it is common in higher education to rely on Microsoft's Office 365 or Google Enterprise Apps for Education as they provide convenient and familiar ways of communication as many of us use these products in our everyday life (when exactly have we *all* become digital archaeologists?). Google Earth, for instance, greatly changed the way we teach, learn, and present archaeology. A wide variety of free or pay-as-you-go e-learning services (such as Coursera, Udemu, etc.) offer Massive Open Online Courses (MOOCs) challenging, shaping, or influencing how archaeology tutors interact with students -especially as educators have to handle an increasing number of students. Archaeology takes part in these platforms⁵ and as such students greatly benefit from cloud applications.

Emerging collaborations between the corporate world and education should not come as a surprise since cloud computation offers multi-sided marketing strategies. A while back ago, Google in cooperation with IBM, established strong ties with universities to fulfil our daily digital needs (Lohr 2007); a market has been created. And overall, archaeology increasingly relies on cloud solutions and computation. But, should we not also explore what cloud is covering/veiling/hindering as we develop more ethical, non-exclusionary and scientific digital approaches to archaeology?

We try to provide a brief answer to our rhetorical question above. Our two examples below are by no means exhaustive. But our hope is that our subjective look at the cloud metaphor can provide seeds for future critical studies. For instance, as we mentioned above many citizen science projects, including archaeology

projects, run on Microsoft Azure cloud computing system. It is the same platform that provides service to the US military (Lockheed Martin 2022; Microsoft *n.d.*). So, we speculate the terms civilian and military amalgamate in the cloud, especially in the age of big data (see Dunne and Sköns 2011). In this particular case, it is not clear to us if the know-how acquired in the civilian sector is not used in the military cloud, and vice versa. To date, we were not able to identify an online Microsoft user agreement that could provide an answer. If we shift our attention to heritage computing we see an equally problematic area. To us it is clear that the necessity to outsource the (digital) curation in the cloud adds further complexity to heritage stakeholder relations. The visitor of the museum is also the user of the platform. And while large and famous museums add more to their fame, smaller and local museums already struggling with budget shortages must also go digital to retain their visibility. The artefact in the museum is now a sociotechnical object that is not static but part of the capitalization process that is always in motion. So, the cloud is a perfect metaphor to guise profit-driven value creation, also in archaeology. It is also in the cloud that labour is transformed, as we are facing a renewed value system (see the section on Transformations).

2.3 The Myth of Inclusivity

We begin with a standard definition of inclusivity. While the term has variable meanings -as there can be no fully inclusive definition- a dictionary definition holds for the reasons it is being used here. According to the Oxford English Dictionary, inclusivity is “[t]he fact or quality of being inclusive; (now) esp. the practice or policy of not excluding any person on the grounds of race, gender, religion, age, disability, etc.” As many can agree, inclusivity is introducing a new norm in research, practice, and teaching in archaeology.

And thanks to digital technologies, more inclusive archaeology is possible more than ever. Co-creation, participation, and democratization are now viable options in archaeological knowledge production. For instance, citizen science is an emerging tool, promising to merge the gap between citizens and our ivory towers. It is also now apparent that citizen science can be beneficial to many, spanning ranges from children (Makuch and Aczel 2020) to the elderly (Barrie *et al.* 2019). But who participates in citizen-science projects? We rephrase to emphasize and set our agenda: who are these citizens we, the archaeologists, are collaborating with? Through these projects do we risk empowering a group of citizens over others?

5 Some notable examples: <https://www.coursera.org/learn/palatine-hill-archaeology-history>, by Sapienza – Università di Roma in Italy; <https://www.coursera.org/learn/truthinourbones-osteoarchaeology-archaeology>, by Universiteit Leiden in the Netherlands; <https://www.coursera.org/learn/wonders-ancient-egypt>, by University of Pennsylvania.

At this moment we pause and claim that the way digitalization works contributes, and considerably, to the social divide in many forms and ways. In the current setup, people with more/better access to digital skills will gain further privileges in society (Ragnedda 2020, 40-3). The digital divide is dynamic in the sense that differential access, use, and capitalization of internet and communication technologies (ICT) is generating new forms of poverty while bolstering existing inequalities (Wessels 2013, 18). Digitalization of services benefits many, but not all; people with better access to ICT have higher participation in the current governance models or are naturally better aware of digital public engagement projects. People with limited access to ICT are further excluded from decision-making (Sanders and Scanlon 2021, 131).

Digitalization excludes three levels (Ragnedda 2020; van Dijk 2013). At the first level, the individual/group does not have the means for connecting to the digital world. Broadband internet is one of the key requirements for digitalization. Globally, 40% of the world's population is excluded from the online world in one way or the other. Material conditions of digitalization are still a concern even in fully connected and developed regions of the world (van Deursen and van Dijk 2019).

At the second level, the digital divide lies in the lack of information and skills for using ICT. The second level divide is intrinsically related to other existing forms of inequalities (Ragnedda 2020, 46). It is true that the digital divide between men and women is almost closed in some countries, but remains high in developing countries and “the reason why fewer women access and use ICT is a direct result of their unfavourable conditions concerning employment, education and income” (Hilbert 2011, 479). ICT pertains to other forms of inequalities in the developed world as well. Women use ICT in lesser frequency (Wasserman and Richmond-Abbott 2005), lower intensity (Hargittai 2010) and with less peripheral diversity (van Deursen and van Dijk 2019).

At the third level, Scheerder *et al.* (2017) and Wei *et al.* (2011) identify the digital divide as the lack of capacity of a person/group to transform or transfer between digital and other capital types. “The position held in the social hierarchy not only influences how individuals access and use ICTs but – being the field in which the seeds of digital experience are sown – also determines the concrete benefits individuals receive from the use of ICTs.” (Ragnedda 2020, 49). That is,

underprivileged individuals and groups are further punished for not being fully integrated into the digital realm as they lack the means for the transformation/transfer of digital capital into other tangible and intangible capital. As people build and promote citizen-science projects, to what extent do they pause and explore -beforehand- at least some of the concerns above? Are archaeologists interested in citizen science or citizen data (Purdam 2014)?

2.4 Digital Inclusivity in Archaeology

There is notable scholarly work contributing to digital inclusivity, especially in the heritage domain (*e.g.*, Simon 2011; van der Hoeven 2020). Familiar to almost all of us, Geographic Information Systems (GIS) is one of the major digital realms where inclusive approaches are critically discussed. Participatory GIS projects, for instance, offer more inclusive research (see Dunn (2007) for a general review and see Larrain and McCall (2019) for a representative archaeological and historical application). Despite successful attempts, Elwood, for instance, warns us participatory approaches also “introduce new tensions and paradoxes into GIS” (2006, 697).

Digital inclusivity in emerging crowdsourcing approaches is a concern in information sciences (*e.g.*, Estellés-Arolas and González-Ladrón-de-Guevara 2012). Crowdsourcing has notable use cases in geographic (See *et al.* 2016) or qualitative analysis (Mathews *et al.* 2018). Archaeologists also conducted notable projects using citizen-science approaches (*e.g.*, Jennings *et al.* 2017; Lambers *et al.* 2019). Crowdsourcing may involve active data generation by participants. However, it is also possible that citizens produce information about heritage in their social media activities, eventually generating a massive online resource. Using this ‘passive’ pool of information researchers can conduct media analysis on a micro/local scale (*e.g.*, Wight 2020) or can ‘mine’ macro/large-scale data (*e.g.*, Rashid and Qasha 2022; Riva *et al.* 2019). Finally, community-involved participatory and inclusive projects, methods, and theories are now more visible, such as archaeogaming (Politopoulos and Mol, this volume).

Despite some key challenges, such as lack of expertise, resources and priorities, geographical dispersion, and community (dis)connection (Harkema and Salt 2017), digital co-creation is still promising an inclusive production of archaeological and heritage knowledge through active participation of the public. In notable examples where there is direct participation, researchers made use of digital worlds to better

understand how people value historic urban landscapes (van der Hoeven 2020), enhanced museum curations and created more inclusive and dynamic histories (Cook and Hill 2019) or developed artefact databases for a better engagement of the local community with fieldwork practices (Moser *et al.* 2020). Another example comes from Çatalhöyük. Morgan (2009) addresses virtual worlds and discusses their potential for better communication with non-expert audiences. Morgan and Eve further challenge us for more “ubiquitous, reflexive, open and participatory archaeology on both the institutional and the individual level” (2012). But if we are ‘all’ digital archaeologists what is the state-of-the-art in true emancipatory archaeology?

In other non-direct/non-voluntary, but still collaborative approaches, scholars can make use of existing data procured by the public. For instance, Grün *et al.* (2004) successfully performed a photogrammetric reconstruction of the now-destroyed Buddhas of Bamiyan, Afghanistan using already available images on the internet. Similar passive approaches are becoming more visible in the analysis of social media relevant to our discipline (*e.g.*, Rashid and Qasha 2022). It must be remembered that scraping social media data for heritage analysis has bottlenecks. Twitter, for instance, provides a biased sample unless the user opts-in for a costly Firehose API (Morstatter *et al.* 2013).

In contested landscapes, the hope lies in the adoption of scholarly work by local communities so that one can “move beyond data-sharing” (Hammer *et al.* 2018, 142). The same reality casts a dark shadow on efforts in preserving the Afghan cultural heritage through participatory activities (*e.g.*, Constantinidis 2016), and digital tools of archaeology fail to support peace and identity-building efforts (Dupree 2002). Archaeologists can play major roles in assisting politically torn countries to manage their heritage. However, digital work in contested landscapes often has to face the analogue reality, as in the case of the heritage of Afghanistan. The promise of the digital dissolves rather rapidly with realpolitik. The promise has geography and is not valid globally.

We shift our focus to Wikipedia as it is known to be a reliable fully open resource, for instance, in higher education (Chen 2010). Rosenzweig (2006) asks if history can be open-source and scrutinizes Wikipedia as an open-access tool. In particular, Marwick and Smith (2021) systematically investigate the representation of UNESCO World Heritage cultural sites on this platform. They identify places in the Global North that are over-represented. In contrast, heritage sites

in South American countries are underrepresented, and inclusivity is the worst for African countries. Furthermore, Wiki articles receive edits mainly from the core Anglosphere countries (UK, USA, Australia, and Canada), suggesting the continuation of (digital) domination over knowledge production. A generic predictor for a Wikipedia editor is a young male with good Internet skills and a high frequency of use (Hargittai and Shaw 2015). So, we ask how inclusive Wikipedia’s information generation is. For us, the digital provides ample opportunities for doing inclusive education, knowledge generation, and its dissemination. On the other hand, we also acknowledge that true inclusivity is possible only when the issues are tackled in everyday analogue life. Otherwise, it is certain that the digital will fail another promise, and inclusivity will remain a myth.

3 TRANSFORMATIONS OF COLLABORATION AND LABOUR

So far, our focus has been on metaphors and myths. We explored cloud computation to highlight how metaphors can veil critical parts of digital transformation in our discipline. And we discussed how digital inclusivity could quickly become a myth as digitalisation continually broadcasts an image of successful change; providing a critical reading of digital transformation in archaeology has been our primary concern⁶. Now we attempt to flesh it out further by focusing on a single example: collaboration, and how collaboration is changing due to digital praxis. The metaphor is appropriate here since it is in the cloud, that archaeologists often collaborate with each other. And with digitalisation, many argue that “[s]ocial media, mobile apps, and teleconferencing platforms allowed for inclusive collaboration” (Dewhurst *et al.* 2014, 467). To understand the true nature of digital collaboration, we can turn our critical attention to the ways in which archaeologists (and humanities scholars in general) collaborate. We argue that archaeological scholarship needs further reflections to challenge the misplaced optimism on collaboration; and how it is -in fact- deeply rooted in digital labour processes.

Collaborative efforts are taking an increasingly large and more explicit position within archaeology

6 It is also possible to reverse our workflow and ask about the role of “archaeology and archaeological information in the digital society” (Huvila 2018).

(and related domains, such as digital humanities and digital heritage) as the field continues to digitize (e.g., Bonacchi and Petersson 2017; Brown 2016; Griffin and Hayler 2018; Kemman 2019; Wright and Richards 2018). However, both in archaeology and related domains critical reflection on the relationship between (academic) collaboration and human labour processes is rare. Among the few cases are the conclusions drawn by Nowviskie (2011, 171). She points out that the role of digital humanities practitioners outside of the ranks of tenured and tenure-track faculty is systematically overlooked in digital humanities research. Related, Mann (2019, 269) observes powerfully that “collaboration, as it is typically practiced [within digital humanities], risks shutting graduate students out of the very scholarship they laboured to produce”. According to Mann (2019, 269) this paradoxical situation comes about since graduate students are often treated as employees in digital collaborative projects with their labour power being commodified. In archaeology, Perry and Beale (2015) focus on the use of digital social media and how such media can be too easily considered collaborative and, as such, unquestionably progressive. They highlight that unjustifiably affirmative discourse used to re-present digital participation (e.g., crowdsourcing, blogging) in archaeology and heritage results often in free labour (in the form of voluntary work) and the risk of exploitation.

For more than a decade, a strong link has been in the making between the concept of collaboration and that of infrastructure. Specifically, the term “infrastructure” started to hype in the 2000s onwards within the European Research Area (Hallonsten 2020), when various “assemblages” started to be referred to as infrastructures. In that context affordance of collaborative research started to be presented as a positive asset for these infrastructures. Arguably, this successful marriage helped both concepts, namely collaboration and infrastructure, to dodge critical reflection: collaborative digital research infrastructures have been presented as an alluring technological innovation, a new way of doing things, and a type of progress. They were praised to promote communication, multivocality, openness, dialogue, and sharing as well as a diffused model of authority and authorship; and, of course, inclusiveness. They have been argued to bring about reliable and visible research results while enabling the aggregation of big and distributed data sets (Edmond 2015, 62-3; McCarty 2012). These data sets are usually hosted in the cloud, providing further means for being visible

while implying an invisible (physical) infrastructure. The European Collaborative Cloud for Cultural Heritage with an intended budget of 110 million euros until 2025 from Horizon Europe is the next major initiative of the European Union in this direction. The cloud would “foster cooperation and co-creation among cultural, creative and technology sectors and will help safeguard European cultural treasures through a digital infrastructure” (ERRIN 2023).

One question that so far escaped empirical attention is whether these statements about collaboration (and cooperation and co-creation) and digital research infrastructures are always accurate – or accurate at all. If they are only conditionally accurate, we need to ask ourselves under which conditions collaborative digital research infrastructures are as progressive as they are described to be. Put differently, how and, perhaps more aptly, when and for whom collaborative digital research infrastructures are different, new and “better” in comparison to their counterparts with an accentuated corporate and commercial logic such as Elsevier and JSTOR (James 2020)?

To unpack these questions, on top of physical infrastructures one also needs to come to terms with the “human dimension” of digital research infrastructures and their highly relational nature. In our opinion, understanding them as “technologies” in the Marxist sense of the word provides a framework. Geographer David Harvey (2018, 9) provides the following definition of the term technology: “For Marx, the question of technology looms large as it does in almost all forms of economic analysis. Marx’s definition is broad and all-encompassing. Technology does not only refer to the machines and tools and energy systems put in motion (the hardware as it were). It also includes organisational forms (divisions of labour, structures of cooperation, corporate forms, etc.) and the software of control systems, time and motion studies, just-in-time production systems, artificial intelligence and the like.” Cloud technology, for instance, is a prime example. The cloud is not only an ever-expandable and powerful but out-of-reach metaphoric space, but it is also made of massive machines, cooling systems and relevant infrastructure, wires, etc. At the same time, the cloud is not merely machines but it comprises an assemblage of socio-technical objects that are the material manifestations of particular intentions and thus, have human and material consequences, ranging from environmental (Monserrate 2022) to privacy and security (Xiao and Xiao 2013).

Some definitions of digital infrastructures match well with the Marxist definition of technology presented here (e.g., Anderson 2013; Crane *et al.* 2009; Brown and Greengrass 2010, 1; Benardou *et al.* 2018, 3). This convergence happens precisely when “social factors” – that is, different forms of human organisation and cooperation – get acknowledged as crucial constitutive elements of digital infrastructures. In other words, approaching digital research infrastructures requires treatment of software, hardware and “the social” (e.g., scholarly practices, user needs, institutional traditions, human labour) as on equal footing, if not inseparable.

A quick etymological investigation is quite revealing. The Concise Oxford Dictionary of English Etymology ties the word with Latin “collaborāre. f. COL- + labor LABOUR.” Col- is assimilated from com- meaning *together*. In other words, as people collaborate, they labour together. So, we naturally ask: could any digital infrastructure still qualify as being collaborative when we consider not a select group, but all agents involved? We draw particular attention to the labour of graduate students and post-doctoral scholars discussed above, who often find themselves in precarious labour appropriation that co-exists with the ideas of and hopes of collaborative knowledge production. Another concern that requires attention here regards the hardware and “the social”. That is, what about the human labour involved in producing material components that comprise collaborative digital research infrastructures? It is a known (but surprisingly under-discussed) fact that materials involved in building and using these infrastructures (such as those that make up computers, mobile phones, tablets, network cables, servers, docking stations, and laptop bags) are almost always produced out-of-sight. How genuinely collaborative can the so-called “collaborative research infrastructures” be when the very hardware that they are built with threatens the well-being of humans that were involved in their production process (e.g., Fuchs 2013, 155-180)?

4 CONCLUSION

We realize our readers will see us painting a rather dark picture of the current state of digital archaeology. Practising archaeology for the sake of practising archaeology is a privileged position. And, as the authors, we acknowledge our privilege of being based in two Benelux countries in tenure(-track) positions. Our everyday life experiences show us that the optimism of digitalization does not chip away from

imbalanced power dynamics within our discipline. A genuinely inclusive practice, research, teaching, communication, dissemination, and outreach are bounded by impasses that are usually -but not always- out of our control. For that, we will keep practising (digital) archaeology and carry optimism for the future. Yet our concern has always been the uncritical adoption and use of digital theories, tools and methodologies. As information and communication technologies advance, archaeologists arguably tend to constantly push the envelope using cutting-edge tools and technologies to move beyond state-of-the-art collectively. In this chapter, we paused and generated a series of questions: where do archaeologists push the envelope? Have archaeologists depleted their existing computational resources in the current affairs of the state-of-the-art so that they have to be constantly on the move, or are they mainly influenced by the socio-technical climate of the data-driven era? Who are the primary drivers of this era, and who benefits the most from the new state-of-the-art? Can archaeologists reimagine and reconfigure how they do things so that our digital advancement does not harm the material life of others? To put it speculatively and bluntly, is digital archaeology creating a new form of colonialist practice, albeit remotely?

In this chapter, we also argued -despite the broadcasted image-, current digital technologies only *appear to* be decentralizing and deterritorializing. In the new connected territories, the winner takes it all (Pesce *et al.* 2019, 1885). Metaphors are hiding the material bases of the digital, further contributing to the invisibility of the disenfranchised. The privileged are also alienating from their labour; as people labour to make use of a “free” product they contribute to its value with their working hours (Fuchs 2014, 131). In other words, labour relations have become more invisible in the metaphoric cloud as people contribute to the myth of a free product.

It appears that the digital divide will remain unless divides in the world are tackled. In some cases, emerging digital tools and approaches consolidate existing biases even though they claim to bring machine *objectivity* as a remedy for human *subjectivity* (Hacıgüzeller, Taylor and Perry 2021). Especially, it is not clear if new promises made through big data, machine learning, and other automation practices can indeed help archaeologists to practice more inclusive and collaborative archaeology at the same time. Yet, our optimism lies in the possibility of other digitalities to invent. We will dig more into this sandbox. And as we play, we hope to:

- Emphasize power relations that are naturally embedded in the digital. This begs the creation of a social theory of digital (van Dijk 2013; Ossewaarde 2019; Roth 2019).
- Highlight digital inequalities. Current literature suggests, digital and other forms of inequalities go hand in hand. The social theory of digital archaeology can directly address these inequalities in all necessary forms, including data activism (Thompson 2020).
- Recognize the digital divide as a human rights and social justice issue (Sanders and Scanlon 2021).

We wrap up with the latest digital promise. As we (re-) enter the era of artificial intelligence and dream of digital twins/minds, the idea of a holodeck rises again. Our old Universal Turing Machine is now truly a “universal fantasy machine” (Murray 1997, 17). So, we ask a final question: whose fantasy is this that we are living in?

REFERENCES

- Al-Busaidi, K.A. 2012. “The Payoff of Corporate Portal Usage in an Academic Institution”. *Campus-Wide Information Systems* 29 (5): 368-79. DOI:10.1108/10650741211275125.
- Alzouma, G. 2005. “Myths of Digital Technology in Africa: Leapfrogging Development?” *Global Media and Communication* 1 (3): 339-56. DOI:10.1177/1742766505058128.
- Amoore, L. 2018. “Cloud Geographies: Computing, Data, Sovereignty”. *Progress in Human Geography* 42 (1): 4-24. DOI:10.1177/0309132516662147.
- Anderson, Sheila. n.d. “What Are Research Infrastructures?” *International Journal of Humanities and Arts Computing* 7 (1-2): 4-23. DOI:10.3366/ijhac.2013.0078.
- Bamforth, D.B. 2002. “Evidence and Metaphor in Evolutionary Archaeology”. *American Antiquity* 67 (3): 435-52. DOI:10.2307/1593821.
- Barrie, H., V. Soebarto, J. Lange, F. Mc Corry-Breen, and L. Walker. 2019. “Using Citizen Science to Explore Neighbourhood Influences on Ageing Well: Pilot Project”. *Healthcare* 7 (4): 126. DOI:10.3390/healthcare7040126.
- Benardou, Agiatis, Erik Champion, Costis Dallas, and Lorna Hughes. 2018. *Cultural Heritage Infrastructures in Digital Humanities*. Routledge. DOI:10.4324/9781315575278.
- Bonacchi, C., and B. Petersson. 2017. “Digital Co-Production in Archaeology. An Editorial.” *Internet Archaeology* 46. DOI:10.11141/ia.46.1.
- Broodman, E. 2017. “White Nationalists Are Flocking to Genetic Ancestry Tests—with Surprising Results.” Accessed April 11, 2023. <https://www.scientificamerican.com/article/white-nationalists-are-flocking-to-genetic-ancestry-tests-with-surprising-results/>
- Brown, S. 2016. “Towards Best Practices in Collaborative Online Knowledge Production”. In *Doing Digital Humanities: Practice, Training, Research*, edited by C. Crompton, R. Jane, and R. Siemens, 47-64. New York: Routledge.
- Brown, S., and M. Greengrass. 2010. “Research Portals in the Arts and Humanities”. *Literary and Linguistic Computing* 25 (1). DOI:10.1093/lc/fqp032.
- Chen, H. 2010. “The Perspectives of Higher Education Faculty on Wikipedia”. *The Electronic Library* 28 (3): 361-73. DOI:10.1108/02640471011051954.
- Christensen, L.T., and J. Cornelissen. 2015. “Organizational Transparency as Myth and Metaphor”. *European Journal of Social Theory* 18 (2): 132-49. DOI:10.1177/1368431014555256.
- Constantinidis, D. 2016. “Crowdsourcing Culture: Challenges to Change”. In *Cultural Heritage in a Changing World*, edited by K.J. Borowiecki, N. Forbes, and A. Fresa, 215-34. Springer. DOI:10.1007/978-3-319-29544-2_13.
- Cook, K., and G. Hill. 2019. “Digital Heritage as Collaborative Process: Fostering Partnerships, Engagement and Inclusivity”. *Studies in Digital Heritage* 3 (1): 83-99. DOI:10.14434/sdh.v3i1.25297.
- Coward, F., and C. Gamble. 2010. “Metaphor and Materiality in Early Prehistory”. In *The Cognitive Life of Things*, edited by L. Malafouris and L. Renfrew, 47-58. Cambridge: McDonald Institute of Archaeological Research.
- Crane, G., B. Seales, and M. Terras. 2009. “Cyberinfrastructure for Classical Philology”. *Digital Humanities Quarterly* 3 (1). DOI:10.31826/9781463219222-005.
- Custer, J.F., T. Eveleigh, V. Klemas, and I. Wells. 1986. “Application of LANDSAT Data and Synoptic Remote Sensing to Predictive Models for Prehistoric Archaeological Sites: An Example from the Delaware Coastal Plain”. *American Antiquity* 51 (3): 572-88. DOI:10.2307/281753.
- CYOP. n.d. “Open Source Software Vs. Software as a Service (SAAS) – Which is Best For You?” Accessed April 11, 2023. https://cyop.net/open_source_vs_software_as_a_service.html.
- de Saint Laurent, C. de. 2018. “In Defence of Machine Learning: Debunking the Myths of Artificial

- Intelligence". *Europe's Journal of Psychology* 14 (4): 734-47. DOI: 10.5964/ejop.v14i4.1823.
- Dewhurst, C.K., D.B. N'Diaye, and M. MacDowell. 2014. "Cultivating Connectivity: Folklife and Inclusive Excellence in Museums". *Curator: The Museum Journal* 57 (4): 455-72. DOI: 10.1111/cura.12085.
- Dunn, C.E. 2007. "Participatory GIS – a People's GIS?" *Progress in Human Geography* 31 (5): 616-37. DOI: 10.1177/0309132507081493.
- Dunne, J.P., and E. Sköns. 2021. "New Technology and the Changing Military Industrial Complex". University of Cape Town: PRISM Working Papers.
- Dupree, Nancy Hatch. 2002. "Cultural Heritage and National Identity in Afghanistan". *Third World Quarterly* 23 (5): 977-89. DOI: 10.1080/0143659022000028549.
- Edgerton, D. 2011. *The Shock of the Old: Technology and Global History Since 1900*. Oxford: Oxford University Press.
- Edmond, J. 2015. "Collaboration and Infrastructure". In *A New Companion to Digital Humanities*, edited by S. Schreibman, R. Siemens, and J. Unsworth, 54-65. John Wiley & Sons. DOI:10.1002/9781118680605.ch4.
- Elwood, S. 2006. "Critical Issues in Participatory GIS: Deconstructions, Reconstructions, and New Research Directions". *Transactions in GIS* 10 (5): 693-708. DOI: 10.1111/j.1467-9671.2006.01023.x.
- ERRIN. 2023. "A cloud for all: European Collaborative Cloud for Cultural Heritage." Accessed April 1, 2023. <https://errin.eu/events/cloud-all-european-collaborative-cloud-cultural-heritage>.
- Estellés-Arolas, E., and F. González-Ladrón-de-Guevara. 2012. "Towards an Integrated Crowdsourcing Definition". *Journal of Information Science* 38 (2): 189-200. DOI: 10.1177/0165551512437638.
- Floridi, L. 2020. "AI and Its New Winter: From Myths to Realities". *Philosophy & Technology* 33 (1): 1-3. DOI: 10.1007/978-3-030-80083-3_6.
- Foucault, M. 1996. "Space, Knowledge and Power". In *Foucault Live (Interviews, 1961-1984)*, edited by S. Lotringer, translated by L. Hochroth and J. Johnston, 335-47. Semiotext(e).
- Fowler, D.D. 1987. "Uses of the Past: Archaeology in the Service of the State". *American Antiquity* 52 (2): 229-48. DOI: 10.2307/281778.
- Freud, S. 1953. "Fragment of an Analysis of a Case of Hysteria (1905 [1901])". In *The Standard Edition of the Complete Psychological Works of Sigmund Freud, Volume VII (1901-1905): A Case of Hysteria, Three Essays on Sexuality and Other Works*, 1-122.
- Fuchs, C. 2014. *Digital Labour and Karl Marx*. Routledge. DOI:10.4324/9781315880075.
- Furlong, K. 2021. "Geographies of Infrastructure II: Concrete, Cloud and Layered (in) Visibilities". *Progress in Human Geography* 45 (1): 190-98. DOI: 10.1177/0309132520923098.
- Gardin, J.-C. 1958. "Four Codes for the Description of Artifacts: An Essay in Archeological Technique and Theory". *American Anthropologist* 60 (2): 335-57. DOI: 10.1525/aa.1958.60.2.02a00090.
- Giaccardi, E. 2012. *Heritage and Social Media: Understanding Heritage in a Participatory Culture*. New York: Routledge.
- González-Martínez, José A., Miguel L. Bote-Lorenzo, Eduardo Gómez-Sánchez, and Rafael Cano-Parra. 2015. "Cloud Computing and Education: A State-of-the-Art Survey". *Computers & Education* 80: 132-51. DOI: 10.1016/j.compedu.2014.08.017.
- Griffin, G., and M.S. Hayler. 2018. "Collaboration in Digital Humanities Research – Persisting Silences". *Digital Humanities Quarterly* 12 (1): 1-33.
- Grün, A., F. Remondino, and L. Zhang. 2004. "Photogrammetric Reconstruction of the Great Buddha of Bamiyan, Afghanistan". *The Photogrammetric Record* 19 (107): 177-99. DOI: 10.1111/j.0031-868X.2004.00278.x.
- Hacigüzeller, P., J.S. Taylor, and S. Perry. 2021. "On the Emerging Supremacy of Structured Digital Data in Archaeology: A Preliminary Assessment of Information, Knowledge and Wisdom Left Behind". *Open Archaeology* 7 (1): 1709-30. DOI: 10.1515/opar-2020-0220.
- Hakenbeck, S.E. 2019. "Genetics, Archaeology and the Far Right: An Unholy Trinity". *World Archaeology* 51 (4): 517-27. DOI: 10.1080/00438243.2019.1617189.
- Hall, M. 1984. "The Myth of the Zulu Homestead: Archaeology and Ethnography". *Africa* 54 (1): 65-79. DOI: 10.2307/1160144.
- Hallonsten, O. 2020. "Research Infrastructures in Europe: The Hype and the Field". *European Review* 28 (4): 617-35. DOI: 10.1017/S1062798720000095.
- Hamilakis, Y. 2017. "Who are you calling Mycenaean?" Accessed April 11, 2023. <https://www.lrb.co.uk/blog/2017/august/who-are-you-calling-mycenaean>.
- Hammer, E., R. Seifried, K. Franklin, and A. Lauricella. 2018. "Remote Assessments of the Archaeological Heritage Situation in Afghanistan". *Journal of Cultural Heritage* 33: 125-44. DOI: 10.1016/j.culher.2017.12.008.
- Hargittai, E. 2010. "Digital Na(t)ives? Variation in Internet Skills and Uses among Members of the

- "Net Generation". *Sociological Inquiry* 80 (1): 92-113. DOI: 10.1080/1369118X.2014.957711.
- Hargittai, E., and A. Shaw. 2015. "Mind the Skills Gap: The Role of Internet Know-How and Gender in Differentiated Contributions to Wikipedia". *Information, Communication & Society* 18 (4): 424-42. DOI:10.1080/1369118X.2014.957711.
- Harkema, C., and J. Salt. 2017. "A Case for Collaboration: Solving Practical Problems in Cultural Heritage Digitization Projects". In *Participatory Heritage*, edited by H. Roued-Cunliffe and A. Copeland, 185-94. London: Facet Publishing. DOI:10.29085/9781783301256.019.
- Harvey, D. 2018. *Marx, Capital, and the Madness of Economic Reason*. Oxford: Oxford University Press.
- Hilbert, M. 2011. "Digital Gender Divide or Technologically Empowered Women in Developing Countries? A Typical Case of Lies, Damned Lies, and Statistics". In *Women's Studies International Forum*, 34:479-89. Elsevier. DOI: 10.1016/j.wsif.2011.07.001.
- Huvila, I. 2018. *Archaeology and Archaeological Information in the Digital Society*. Routledge. DOI:10.4324/9781315225272.
- Hymes, D.H. 1963. "Conferences". *Current Anthropology* 4 (1): 123-29.
- James, J.E. 2020. "Pirate Open Access as Electronic Civil Disobedience: Is It Ethical to Breach the Paywalls of Monetized Academic Publishing?" *Journal of the Association for Information Science and Technology* 71 (12): 1500-1504. DOI:10.1002/asi.24351.
- Jennings, E., M. Dobрева, and A. Devreni-Koutsouki. 2017. "Towards User Engagement Models for Citizen Science". In *Cultural Heritage Communities*, edited by L. Ciolfi, A. Damala, E. Hornecker, M. Lechner, and L. Maye, 78-95. New York: Routledge.
- Jennings, M.K., and V. Zeitner. 2003. "Internet Use and Civic Engagement: A Longitudinal Analysis". *Public Opinion Quarterly* 67 (3): 311-34. DOI:10.1086/376947.
- Kemman, M. 2019. "Boundary Practices of Digital Humanities Collaborations". *DHBenelux Journal* 1: 1-24.
- Kersten, T. P., and M. Lindstaedt. 2012. "Potential of Automatic 3D Object Reconstruction from Multiple Images for Applications in Architecture, Cultural Heritage and Archaeology". *International Journal of Heritage in the Digital Era* 1 (3): 399-420. DOI:10.1260/2047-4970.1.3.399.
- Khmelevsky, Y., and V. Voytenko. 2010. "Cloud Computing Infrastructure Prototype for University Education and Research". In *Proceedings of the 15th Western Canadian Conference on Computing Education*, 1-5. DOI:10.1145/1806512.1806524.
- Kirschner, P.A., and P. De Bruyckere. 2017. "The Myths of the Digital Native and the Multitasker". *Teaching and Teacher Education* 67: 135-42. DOI:10.1016/j.tate.2017.06.001.
- Lakoff, G., and M. Johnson. 2008. *Metaphors We Live By*. University of Chicago Press. DOI: 10.7208/chicago/9780226470993.001.0001.
- Lambers, K., W.B. Verschoof-van der Vaart, and Q.P.J. Bourgeois. 2019. "Integrating Remote Sensing, Machine Learning, and Citizen Science in Dutch Archaeological Prospection". *Remote Sensing* 11 (7): 794. DOI:10.3390/rs11070794.
- Larrain, A. Á., and M.K. McCall. 2019. "Participatory Mapping and Participatory GIS for Historical and Archaeological Landscape Studies: A Critical Review". *Journal of Archaeological Method and Theory* 26 (2): 643-78. DOI:10.1007/s10816-018-9385-z.
- Lepawsky, J. 2015. "The Changing Geography of Global Trade in Electronic Discards: Time to Rethink the E-waste Problem". *The Geographical Journal* 181 (2): 147-59. DOI:10.1111/geoj.12077.
- Light, J.S. 1999. "When Computers Were Women". *Technology and Culture* 40 (3): 455-83. DOI:10.1353/tech.1999.0128.
- Lockheed Martin. 2022. "Lockheed Martin Collaborates With Microsoft To Advance 5G.MIL® Technologies Using Microsoft Azure". Accessed April 11, 2023. <https://news.lockheedmartin.com/2022-02-27-lockheed-martin-collaborates-microsoft-advance-5G-MIL-technologies-microsoft-azure>.
- Lohr, S. 2007. "Google and I.B.M. Join in "Cloud Computing" Research". *The New York Times*, 2007.
- Lynch, S. 2017. "Andrew Ng: Why AI Is the New Electricity". *Insights by Stanford Business*, 2017. <https://www.gsb.stanford.edu/insights/andrew-ng-why-ai-new-electricity>.
- Maguire, J., and B.R. Winthereik. 2021. "Digitalizing the State: Data Centres and the Power of Exchange". *Ethnos* 86 (3): 530-51. DOI:10.1080/00141844.2019.1660391.
- Makuch, K.E., and M.R. Aczel. 2020. "Eco-Citizen Science for Social Good: Promoting Child Well-Being, Environmental Justice, and Inclusion". *Research on Social Work Practice* 30 (2): 219-32. DOI:10.1177/1049731519890404.
- Mallory, J. P. 1991. *In Search of the Indo-Europeans: Language, Archaeology, and Myth*. Thames and Hudson. DOI:10.1515/pz-1992-0118.

- Mann, R. 2019. "Paid to Do but Not to Think: Reevaluating the Role of Graduate Student Collaborators". In *Debates in the Digital Humanities 2019*, edited by M.K. Gold and L.F. Klein, 268-78. Minnesota: University of Minnesota Press Minneapolis.
- Marwick, B., and P. Smith. 2021. "World Heritage Sites on Wikipedia: Cultural Heritage Activism in a Context of Constrained Agency". *Big Data & Society* 8 (1): 1-19. DOI:10.1177/205395172111017304.
- Massey, G., and M. Ehrensberger-Dow. 2017. "Translating Conceptual Metaphor: The Processes of Managing Interlingual Asymmetry". *Research in Language* 15 (2): 173-89. DOI:10.1515/rela-2017-0011.
- Mathews, A., S. Farley, L. Hightow-Weidman, K. Muessig, S. Rennie, and J.D. Tucker. 2018. "Crowdsourcing and Community Engagement: A Qualitative Analysis of the 2BeatHIV Contest". *Journal of Virus Eradication* 4 (1): 30-36. DOI:10.1016/S2055-6640(20)30239-9.
- Matsui, Yuma, Aaron Gidding, Thomas E. Levy, Falko Kuester, and Thomas A. DeFanti. 2012. "Portable Data Management Cloud for Field Science". In *2012 IEEE Fifth International Conference on Cloud Computing*, 1000-1001. IEEE. DOI:10.1109/CLOUD.2012.68.
- Mazzocchi, F. 2015. "Could Big Data Be the End of Theory in Science? A Few Remarks on the Epistemology of Data-driven Science". *EMBO Reports* 16 (10): 1250-55. DOI:10.15252/embr.201541001.
- McCarty, W. 2012. "Collaborative Research in the Digital Humanities". In *Collaborative Research in the Digital Humanities*, edited by M. Deegan and W. McCarty, 1-10. Farnham: Ashgate. DOI:10.4324/9781315572659.
- Microsoft. n.d. "Azure for US Department of Defense". Accessed April 11, 2023. <https://azure.microsoft.com/en-us/explore/global-infrastructure/government/dod/>.
- Monserate, S.G. 2022. "The Cloud Is Material: On the Environmental Impacts of Computation and Data Storage". *MIT Case Studies in Social and Ethical Responsibilities of Computing* Winter 2022. DOI:10.21428/2c646de5.031d4553.
- Morgan, C., and S. Eve. 2012. "DIY and Digital Archaeology: What Are You Doing to Participate?" *World Archaeology* 44 (4): 521-37. DOI:10.1080/00438243.2012.741810.
- Morgan, C.L. 2009. "(Re) Building Çatalhöyük: Changing Virtual Reality in Archaeology". *Archaeologies* 5 (3): 468-87. DOI:10.1007/s11759-009-9113-0.
- Morstatter, F., J. Pfeffer, H. Liu, and K.M. Carley. 2013. "Is the Sample Good Enough? Comparing Data from Twitter's Streaming Api with Twitter's Firehose". In *Seventh International AAAI Conference on Weblogs and Social Media*. AAAI Press.
- Moser, S., D. Glazier, J.E. Phillips, L.N. El Nemr, M.S. Mousa, R.N. Aiesh, S. Richardson, A. Conner, and M. Seymour. 2002. "Transforming Archaeology through Practice: Strategies for Collaborative Archaeology and the Community Archaeology Project at Quseir, Egypt". *World Archaeology* 34 (2): 220-48. DOI:10.1080/0043824022000007071.
- Murray, J. H. 2017. *Hamlet on the Holodeck, Updated Edition: The Future of Narrative in Cyberspace*. Cambridge MA: MIT Press.
- Netanyahu, B. 2019. "There's no connection between the ancient Philistines and the modern Palestinians, whose ancestors came from the Arabian Peninsula to the Land of Israel thousands of years later". Twitter, July 7, 2019 2:08 p.m. <https://twitter.com/netanyahu/status/1147824702360100864>.
- Nowviskie, B. 2011. "Where Credit Is Due: Preconditions for the Evaluation of Collaborative Digital Scholarship". *Profession*, 169-81. DOI:10.1632/prof.2011.2011.1.169.
- Olsen, Bjørnar. 1986. "Norwegian Archaeology and the People without (Pre-) History: Or How to Create a Myth of a Uniform Past". *Archaeological Review from Cambridge* 5 (1): 25-42.
- Ossewaarde, M. 2019. "Digital Transformation and the Renewal of Social Theory: Unpacking the New Fraudulent Myths and Misplaced Metaphors". *Technological Forecasting and Social Change* 146: 24-30. DOI:10.1016/j.techfore.2019.05.007.
- Penn, J. 2021. "Algorithmic Silence: A Call to Decomputerize". *Journal of Social Computing* 2 (4): 337-56. DOI:10.23919/JSC.2021.0023.
- Perry, S., and N. Beale. 2015. "The Social Web and Archaeology's Restructuring: Impact, Exploitation, Disciplinary Change". *Open Archaeology* 1 (1). DOI:10.1515/opar-2015-0009.
- Pesce, D., P. Neirotti, and E. Paolucci. 2019. "When Culture Meets Digital Platforms: Value Creation and Stakeholders' Alignment in Big Data Use". *Current Issues in Tourism* 22 (15): 1883-1903. DOI:10.1080/13683500.2019.1591354.
- Philip, K., L. Irani, and P. Dourish. 2012. "Postcolonial Computing: A Tactical Survey". *Science, Technology, & Human Values* 37 (1): 3-29. DOI:10.1177/0162243910389594.
- Purdam, K. 2014. "Citizen Social Science and Citizen Data? Methodological and Ethical Challenges for

- Social Research". *Current Sociology* 62 (3): 374-92. DOI:10.1177/0011392114527997.
- Ragnedda, M. 2020. *Enhancing Digital Equity: Connecting the Digital Underclass*. Springer International Publishing. <https://books.google.nl/books?id=OUD2DwAAQBAJ>.
- Ramel, D. 2021. "Cloud Computing and Open Source: It's Complicated". Accessed April 11, 2023. <https://virtualizationreview.com/articles/2021/06/22/cloud-open-source.aspx>.
- Rashid, S.F., and R.P. Qasha. 2022. "Extracting and Archiving Data from Social Media to Support Cultural Heritage Preservation in Nineveh". In *2022 International Conference on Computer Science and Software Engineering (CSASE)*, 295-300. IEEE. DOI:10.1109/CSASE51777.2022.9759782.
- Riva, P., D. Agostino, and M. Arnaboldi. 2019. "Online Reviews for Public Service Personalization: The Case of Italian Museums". In *XXX Riunione Scientifica Annuale Associazione Italiana Di Ingegneria Gestionale 2019*. Torino.
- Rodgers, D., and B. O'Neill. 2012. "Infrastructural Violence: Introduction to the Special Issue". *Ethnography* 13 (4): 401-12. DOI:10.1177/1466138111435738.
- Roguski, P. 2020. "The Geopolitics of Cloud Computing". Geopolitics of Emerging and Disruptive Technologies. The Kosciuszko Institute.
- Rosenzweig, R. 2006. "Can History Be Open Source? Wikipedia and the Future of the Past". *The Journal of American History* 93 (1): 117-46. DOI:10.2307/4486062.
- Roth, S. 2019. "Digital Transformation of Social Theory. A Research Update". *Technological Forecasting and Social Change* 146: 88-93. DOI:10.1016/j.techfore.2019.05.016.
- Rubio-Campillo, Xavier. 2015. "Large Simulations and Small Societies: High Performance Computing for Archaeological Simulations". In *Agent-Based Modeling and Simulation in Archaeology*, 119-37. Springer. DOI:10.1007/978-3-319-00008-4_6.
- Sanders, Cynthia K., and Edward Scanlon. 2021. "The Digital Divide Is a Human Rights Issue: Advancing Social Inclusion through Social Work Advocacy". *Journal of Human Rights and Social Work*, 1-14.
- Scheerder, A., A. Van Deursen, and J. Van Dijk. 2017. "Determinants of Internet Skills, Uses and Outcomes. A Systematic Review of the Second-and Third-Level Digital Divide". *Telematics and Informatics* 34 (8): 1607-24. DOI:10.1016/j.tele.2017.07.007.
- See, L., P. Mooney, G. Foody, L. Bastin, A. Comber, J. Estima, S. Fritz, N. Kerle, B. Jiang, M. Laakso, H. Liu, G. Milčinski, M. Nikšič, M. Painho, Andrea Pódör, A. Olteanu-Raimond, and M. Rutzinger. 2016. "Crowdsourcing, Citizen Science or Volunteered Geographic Information? The Current State of Crowdsourced Geographic Information". *ISPRS International Journal of Geo-Information* 5 (5): 55. DOI:10.3390/ijgi5050055.
- Simon, N. 2011. "Participatory Design and the Future of Museums". In *Letting Go? Sharing Historical Authority in a User-Generated World*, edited by B. Adair, B. Filene, and L. Koloski, 18-33. Philadelphia: The Pew Center for Arts & Heritage. DOI:10.4324/9780429333743-2.
- Smith, A. 2007. "Mapped Landscapes: The Politics of Metaphor, Knowledge, and Representation on Nineteenth-Century Irish Ordnance Survey Maps". *Historical Archaeology* 41: 81-91. DOI:10.1007/BF03376995.
- Thompson, T.L. 2020. "Data-Bodies and Data Activism: Presencing Women in Digital Heritage Research". *Big Data & Society* 7 (2): 2053951720965613. DOI:10.1177/2053951720965613.
- Tunguz, T. 2021. "The Identity Crisis Facing Open Source Companies in the Cloud". Accessed April 11, 2023. <https://tomtunguz.com/open-source-cloud-identity-crisis/>.
- Van Der Hoeven, A. 2020. "Valuing Urban Heritage Through Participatory Heritage Websites: Citizen Perceptions of Historic Urban Landscapes". *Space and Culture* 23 (2): 129-48. DOI:10.1177/1206331218797038.
- Van Deursen, A.J.A.M., and J.A.G.M Van Dijk. 2019. "The First-Level Digital Divide Shifts from Inequalities in Physical Access to Inequalities in Material Access". *New Media & Society* 21 (2): 354-75. DOI:10.1177/1461444818797082.
- Van Dijk, J.A.G.M. 2013. "A Theory of the Digital Divide". In *The Digital Divide*, edited by M. Ragnedda and W. Glenn, 29-51. Taylor & Francis.
- Vecchio, P., F. Mele, L. Tommaso De Paolis, I. Epicoco, M. Mancini, and G. Aloisio. 2015. "Cloud Computing and Augmented Reality for Cultural Heritage". In *International Conference on Augmented and Virtual Reality*, 51-60. Springer. DOI:10.1007/978-3-319-22888-4_5.
- Wasserman, I.M., and M. Richmond-Abbott. 2005. "Gender and the Internet: Causes of Variation in Access, Level, and Scope of

- Use". *Social Science Quarterly* 86 (1): 252-70. DOI:10.1111/j.0038-4941.2005.00301.x.
- Webster, J.G. 2017. "Three Myths of Digital Media". *Convergence* 23 (4): 352-61. DOI:10.1177/1354856517700385.
- Wei, K., H. Teo, H.C. Chan, and B.C.Y. Tan. 2011. "Conceptualizing and Testing a Social Cognitive Model of the Digital Divide". *Information Systems Research* 22 (1): 170-87. DOI:10.1287/isre.1090.0273.
- Weinberger, D. 2017. "Our Machines Now Have Knowledge We'll Never Understand." Accessed April 11, 2023. <https://www.wired.com/story/our-machines-now-have-knowledge-well-never-understand/>.
- Wessels, B. 2013. "The Reproduction and Reconfiguration of Inequality: Differentiation and Class, Status and Power in the Dynamics of Digital Divides". In *The Digital Divide*, edited by M. Ragnedda and W.G. Muschert, 17-28. London: Routledge.
- Wight, A.C. 2020. "Visitor Perceptions of European Holocaust Heritage: A Social Media Analysis". *Tourism Management* 81: 104142. DOI:10.1016/j.tourman.2020.104142.
- Wolinsky, H. 2019. "Ancient DNA and Contemporary Politics: The Analysis of Ancient DNA Challenges Long-held Beliefs about Identity and History with Potential for Political Abuse". *EMBO Reports* 20 (12): e49507. DOI:10.15252/embr.201949507.
- Wright, H., and J.D. Richards. 2018. "Reflections on Collaborative Archaeology and Large-Scale Online Research Infrastructures". *Journal of Field Archaeology* 43 (sup1): S60-67. DOI:10.1080/00934690.2018.1511960.
- Xiao, Z., and Y. Xiao. 2013. "Security and Privacy in Cloud Computing". *IEEE Communications Surveys & Tutorials* 15 (2): 843-59. DOI:10.1109/SURV.2012.060912.00182.
- Yang, S., M. Hou, P. Huo, A. Li, and L. Jiang. 2020. "A Cloud Computing Platform to Support Digital Heritage Application Using a Service-Oriented Approach". *The International Archives of Photogrammetry, Remote Sensing and Spatial Information Sciences* 43: 1497-1504. DOI:10.5194/isprs-archives-XLIII-B2-2020-1497-2020.
- Zernik, A. 2019. "The Invisible Hand, the Regulatory Touch, or the Platform's Iron Grip?" Rochester: SSRN.
- Ziewitz, M. 2016. "Governing Algorithms: Myth, Mess, and Methods". *Science, Technology, & Human Values* 41 (1): 3-16. DOI:10.1177/0162243915608948.

Data Exchange Protocol in Dutch Archaeology

Milco Wansleeben, Walter Laan and Ronald Visser

1 INTRODUCTION

Around 15 years ago, a problem in Dutch archaeology started to become more and more apparent. Owing to the new Malta legislation, the number of archaeological fieldwork projects being conducted by commercial archaeology units in the Netherlands rose precipitously. The units were obliged to deposit their finds and documentation at the designated archaeological depot in the province or municipality within two years after finishing a project. Many of these units operated nationally and were confronted with a wide variety of rules and regulations connected to this deposit process. For each and every depot, they were required to provide different documents. Attempts in the early 2000s to promote the use of a single data management system at all depots had failed (Boogert 2006, 26; Taayke 2003). An exploratory study (Sueur *et al.* 2008) suggested the introduction of a single standardised XML data exchange format for the intermediate collection of data about the items delivered by any archaeology unit to any depot. This delivery slip (*'pakbon'*), also known as the SIKB0102 protocol, was introduced in around 2011 but was not widely adopted for a long time following its introduction. Only a few early adopters among the commercial units had prepared their excavation management software for the export of an XML exchange document.

From a relatively recent report, "Verder graven in depots" (Erfgoedinspectie 2018, 28):

"Wat betreft de pakbon geldt hetzelfde als bij de provinciale depots: er worden vrijwel geen pakbonnen aangeleverd. En er is slechts één gemeentelijk depot dat de pakbon kan inlezen. Veel gemeentelijke depotbeheerders zien geen meerwaarde in de pakbon voor het eigen depot. Degenen die sympathiek staan tegenover het oorspronkelijke idee van één standaard voor aanlevering van vondsten en documentatie, vinden dat de uitwerking daarvan in de huidige vorm niet voldoet. Enkele depots stellen desalniettemin het leveren van een pakbon verplicht, maar hebben daarbij ervaren dat slechts weinig bedrijven een pakbon (kunnen) leveren."

"For the municipalities, the situation with the digital exchange protocol is more or less the same as with the provinces: these are hardly ever used. Only one municipality depot is capable of importing the SIKB0102 document. Many managers from the municipality depots don't feel the digital delivery slip offers additional value for their organization. Some embrace the original idea of having one standard document for the delivery of finds and documentation, but consider the implementation in its current form inadequate. Although a few depots have made the protocol compulsory, experience has shown that only a few commercial units are able to provide it."

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This situation changed quickly after the province of Noord-Brabant (*Provinciaal Depot Bodemvondsten*) took the initiative to develop software that could read the SIKB0102 protocol, in a collaborative effort with a number of provincial archaeological depots (Meffert 2018). From that moment onwards, the supply and demand for this digital data exchange increased, and depots made its use compulsory for new projects. Unfortunately, many commercial units have since struggled with the implementation, encountering many practical obstacles and troublesome discussions with the provincial depots. The technical implementation of the SIKB0102 protocol turns out to be so complicated that many ‘average’ archaeologists are dropping out. This illustrates a huge technological gap between the ‘whiz kids’ in the SIKB0102 technical committee and the archaeologists performing the actual work at archaeological research projects and at the depots. Many archaeologists consider the exchange format to be a black box, are unable to understand the content and cannot solve the problems that arise in the process of depositing finds and documentation.

Archol BV is one of the commercial archaeological units in the Netherlands that was an early adopter of this data exchange protocol. Over the years, several versions of the protocol have been implemented in its excavation registration system, which is based on Microsoft Access. Other Dutch archaeological organizations regularly ask Archol for assistance in the use and implementation of the SIKB0102 protocol. Based on these experiences, this article tries to answer a few questions:

- Were there any mistakes made during the introduction of SIKB0102?
- What is the exact nature of the problem(s)?
- What are possible solutions?
- Which components are still needed in order to make the *pakbon* a success?

2 KNA AND SIKB0102

Dutch archaeology has seen some major changes since the Malta treaty was introduced (1992) and implemented (2006) in the Netherlands through what has been referred to since 2015 as the ‘*Erfgoedwet*’ (integral cultural heritage law). Today, many (semi-)commercial, governmental, and public organizations are involved in heritage management. These organizations are involved in a wide range of tasks, from providing advice to municipalities, undertaking process management, heritage mapping,

surveying, conducting excavations, carrying out material analysis, and engaging in knowledge dissemination. In order to maintain minimal quality requirements, a set of protocols has been agreed upon for each of the steps in the heritage trajectory. These requirements are laid out in the quality standard for Dutch archaeology (KNA: *Kwaliteitsnorm Nederlandse Archeologie*). These protocols specify tasks, documents, and personnel for archaeological research both on land and under water. In addition, organizations that perform excavations or any other type of research that destroys the soil archive must be certified and registered. These protocols are maintained by the Dutch archaeological community and are updated every few years (version 4.1 is currently in force). A foundation for quality assurance in soil management (SIKB: *Stichting Infrastructuur Kwaliteitsborging Bodembeheer*) organizes the workflow and maintains and publishes these standards and protocols on its website (www.sikb.nl/archeologie).

The protocol 4004 (Excavations on Land) also includes the required steps for depositing the finds, samples, and documentation at the end of the archaeological process (OS17). Within the Netherlands, there is an agreement that archaeologists will publish their results within two years after finishing the fieldwork, although this is not always possible, especially when it comes to large-scale excavations. During the pre-publication period, the archaeological objects and (digital and analogue) documentation will remain stored at the excavating organization. After the results are published, the objects and documents are to be transferred to the designated depot at a province or municipality. The province or municipality is assigned as the legal owner of the archaeological discoveries by the *Erfgoedwet*. To make this deposit process as smooth as possible, a number of inventory lists must be presented to the depot beforehand. These include a list of boxes containing the finds or samples, a list of field drawings, a list of digital files (including the digital photos), and a list of binders and reports. With these lists, the depot knows what they will receive and can check whether the documentation is properly done. In the past, individual depots had their own sets of requirements for these inventory lists, but this has now been harmonised in this digital delivery slip (*‘pakbon’*). The *pakbon* (as part of OS17) is a digital document with a fixed, prescribed structure and standardised content. Additional information has been added to this delivery slip over the years, including the description

The Forum on Information Standards in Heritage (FISH) describes a standard and vocabulary (MIDAS Heritage) for a uniform description of the historic environment (www.heritage-standards.org.uk/midas-heritage/). In 2004, a FISH Interoperability Toolkit was developed by Oxford-ArchDigital that serves as an aid for efficient data exchange and archiving via a MIDAS XML document. In 2012 this was adapted by the Archaeology Data Service. The toolkit included tools for mapping data schemes and vocabularies to the Midas Heritage standard and an XML validator (www.heritage-standards.org.uk/fish-interoperability-toolkit-archived/). From 2015 onwards, this XML toolkit is no longer supported, owing to the lack of implementation.

Figure 1: The FISH interoperability toolkit is unfortunately no longer supported.

of non-physical items such as archaeological features, structures, and persons involved. This document has grown into more of a general-purpose data exchange document, making it very versatile and ready for the exchange of any archaeological information between any archaeological organizations. It is implemented as an XML document and referred to as the SIKB0102 protocol.

The original possibility for data exchange between archaeological organizations in the Netherlands was put forward in 2008 in an exploratory study in the Vestigia Rapport V513 (Sueur *et al.* 2008; Verhagen *et al.* 2011). This was initiated by the SIKB and inspired by the SIKB0101 protocol that already existed for soil technical engineers and the FISH protocol (figure 1) that existed in the UK for archaeologists (Gilman and Newman 2007).

The SIKB0102 protocol was introduced in the KNA in 2011 (SIKB 2011). Formally, it became a compulsory format in Dutch archaeology for new projects from that point onwards (www.forumstandaardisatie.nl/open-standaarden/verplicht). However, only a few archaeological organizations immediately implemented it (voluntarily) in their day-to-day practice. Many were hesitant for a long time, for the reasons discussed below.

3 SIKB0102 XML FILE FORMAT

The data exchange format (protocol SIKB0102) has been carefully designed over a long period of time,

```
<sikb0102>
  <project>
    <project_name>
    <start_date>
    <project_identifier>
    <research_type>
    <description>
    <authority>
      <person_identifier>
    <contractor>
      <person_identifier>
    <designated_depot>
```

Figure 2: XML-like snippet with selected and translated elements (tags) of the start of the exchange format, without namespace.

```
<easymetadata>
  <titles>
    <title>
      <alternative_title>
  <subjects>
    <subject>
  <dates>
    <date>
    <date_created>
    <date_available>
    <date_submitted>
  <coverage>
    <spatial>
      <point>
        <x>
        <y>
    <temporal>
```

Figure 3: XML-like snippet with simplified (adjusted) version of some of the tags of the DANS EASY dataset metadata, without namespaces.

following multiple design sessions with a group of mainly ICT-trained ‘computer’ archaeologists. The initial structure (Sueur *et al.* 2008) is still visible in the first part of the XML document, the project description (figure 2). Here, information about the project and actors involved is stored in a hierarchical structure that is almost readable by humans.

```

<archis3>
  <events>
    <event>
      <event_identifier>
      <event_start_date>
      <event_methodology_code>
      <event_methodology_label>
      <find_locations>
        <find_location>
          <municipality>
          <toponym>
          <x-coordinate>
          <y-coordinate>
          <finds>
            <find>
              <amount>
              <material>
              <type>
              <start_date>
              <end_date>
            <features>
              <feature>
                <amount>
                <type>

```

Figure 4: XML-like snippet with selected (translated) tags from the Archis 3 project event data, as stored in the national Archis 3 database at the RCE.

```

<sikb0102 id="3307ce94-7a05-4185-9f0f-2de69f3f88a1" version="4.1.0">
  <project id="ae628cde-9bd7-4c4b-9289-7138f0c0bb43">
  <organization id="449ad8b2-b1dd-41c9-983e-39e3d22b077f">
  <person id="0ab1d5f5-fa03-4571-b6f4-406deb2222bc">
  <person id="e9abc724-9805-449d-b657-2d2ca7643f7f">
  <person id="bc3dc3ec-ef03-424f-89a1-0f732d9799fd">
  <file id="04785ae0-7d5f-43b9-9bc4-d55bb9aa5617">
  <file id="f17b5cce-d2de-4614-887c-a66dde17ae89">
  <file id="89912ec1-6722-44a1-82fd-fd3154ced52b">
  <find id="e77038a6-2285-422d-8340-ccebb037db17">
    <source_identifier>
    <context_UUID>
    <box_UUID>
  <find id="4aa5f7f5-7919-4c4d-9300-afa62a8f8bdd">
  <find id="b59c92e9-0924-464a-bfb9-0b2591fa0528">
  <feature id="8f0da90c-7aba-4a7d-a8e0-b1881cbce351">
  <feature id="7752c3d8-a565-4d5b-a5b6-551c628bcd9f">
  <feature id="12de5b57-8752-4705-aafd-9949a306249b">
  <photo id="c222573c-7e3d-4e92-bca1-98c14d17a247">
  <photo id="74d8d0ea-4662-458d-83f9-677bbb93ec79">
  <photo id="1a7f30c0-44c5-4eee-9f08-6db3482b317c">

```

Figure 5: XML-like snippet with selected (translated) parts of the SIKB0102 protocol to illustrate the object-oriented characteristics.

This part of the document can be read by archaeologists once opened in a web browser, an advanced text editor (like Notepad++), or a special XML editor. It is easy to find information, identify errors, and make corrections.

Many (archaeological) organizations that use XML for data exchange use this hierarchical (nested) property of XML, in order to make the often-complex structure of the information manageable. Two examples from Dutch archaeology are presented below: figure 3 is the metadata export from a dataset in the DANS data archive (EASY), and figure 4 contains a project description from Archis 3 at the Cultural Heritage Agency (RCE).

Both archaeological examples show a hierarchy that represents the underlying data model. Archis, for instance, stores research events that can result in 0, 1, or many find locations, which can yield (any number of) finds and/or archaeological features. This is a hierarchy that reflects the 1-to-many relationship between tables, which is familiar from relational database designs. It is immediately clear to which find location, discovered in which event, a find belongs. Most web browsers even allow end users to expand or hide some of the (nested) branches of the tree to obtain an overview more quickly in the often extensive XML documents.

The simple hierarchical model shown in the XML examples above could have been a template for the SIKB0102 format: starting with a single (main) branch for the project, and branching out to several major entities such as find boxes, documentation, and find locations. A branch for the find locations could have included further (sub-)branches for samples, finds, and features. A branch for the documentation could have included (sub-)branches with attributes about (field) drawings, photos, reports, and files. How such a hierarchy would actually be implemented in the XML does depend on arbitrary decisions, given the recognised fact that archaeological data does not follow a single simple hierarchy (Boasson and Visser 2017). For instance, finds are not only related to find locations; they are also stored in boxes and illustrated on (field) drawings and photos. Features are documented through photos, where information about the same features is part of cross-section drawings and associated with surveying (X, Y, Z) data. The various entities documented during an archaeological project have a large number of potential relationships. The information is therefore generally stored in a relational database that enables us to dynamically

create links between the various parts of our data whenever needed by using a query. A static XML structure would hold only one of the possible representations.

The design team of the SIKB0102 protocol therefore wanted to combine a more relational database- and an object-oriented approach. They used a technical structure that is very similar to the way Linked Open Data (LOD) is modelled. The XML document contains, for the most part, a (very) long list of all possible information objects, in more or less alphabetical order. It simply lists all of the find boxes, along with their properties, followed by flat lists of all the finds, corings, drawings, photos, people, organizations, features, structures, and so on. Each information object is uniquely identified with a UUID (Universally Unique Identifier). This identifier serves as the key for creating relationships between the information objects. A find will have its own UUID and properties for an (indirect) link to the discovery location (context_UUID) and to the box in which it is now stored (box_UUID) (figure 5). This object-oriented data model does provide more flexibility in coping with archaeological data from a wide variety of excavations (Boasson and Visser 2017). One of the first to adapt this in archaeology was the Swedish Intrasis software (www.intrasis.com) from the Swedish National Heritage Board, a general-purpose excavation documentation system. The same principles were adapted in the Netherlands in, for example, the ArcheoLINK software from the private company QLC BV (nowadays part of TijdLab) and the ODILE software from the archaeological company RAAP BV.

One of the downsides of this approach is that the (main) hierarchy (relationships) is not explicitly included in the structure of the XML document. This means that to the average archaeologist, this document is unreadable and is just an arbitrary flat list of entities that are interconnected in an inextricable knot by their arbitrary (UUID) identifiers, which archaeologists no longer recognize as the find number printed on the find label or the filename of the digital photo.

4 PRACTICAL PROBLEMS

Is this object-oriented (Linked Open Data-like) model a (big) problem? Some archaeologists feel it isn't, as the data exchange document is not intended for humans to read. Rather, it is a protocol for facilitating communication between a computer and a computer. Commercial units should invest in an additional piece of software that creates the proper XML document, and the depots should likewise invest in the import

software. However, there are a few arguments that complicate the matter, as explained below.

In many cases, there is a need for personal communication between employees of the commercial unit and the depot about the content of the XML document. This could arise, for example, in the case used in a request for additional information (*e.g.*, this object is used in the publication, but not included in the *pakbon*), an explanation of why some samples are no longer stored in one of the boxes, or a request to correct a few (minor) mistakes. These discussions regularly become laborious and troublesome. The depots have problems defining the exact issue (*e.g.*, there is “something” wrong with the samples, since the import tool is rejecting the *pakbon*), and the commercial unit has trouble pinpointing the records that must be added or changed in order to solve the problem. The XML does not provide a simple and clear basis for the discussion (*e.g.*, “here at line 34567, a value is used that is not allowed”). As a result, both sides send many messages back and forth to explain things in more detail, until frustration arises on both sides: “You made these changes, but now something else has become incorrect...”

The conversion to an object-oriented model from a relational database is not easy, nor is it familiar to many Dutch archaeologists. It requires highly specialised knowledge about:

- technical issues, such as conventions used in UML, XML, XSD, namespaces and the use of UUIDs. The conversion is not a matter of a few simple queries. Rearranging the data tables often also requires some programming skills (*e.g.*, SQL, VBA).
- the actual archaeological content and how the commercial units’ tables and fields correspond to the SIKB0102 entities. To comply with the SIKB thesauri (enumerations), a detailed mapping (concordance) with the prescribed fields and values is required.

The required investments (in terms of both time and money) are substantial, and many Dutch archaeological organizations struggle with that.

- Many commercial units are relatively small companies, with material specialists at one end of the scale, since they often operate as single-handed (sub)contractors. They sometimes even lack the knowledge to create proper databases and work in a less formal manner with small datasets in

spreadsheets. Some smaller units have already joined forces to invest collaboratively in a database system with a SIKB0102 export.

- Even some larger archaeological organizations, such as the RCE and the University of Groningen, have recently asked Archol BV for assistance in implementing the SIKB0102 protocol.
- Provincial depots also struggle to make the required investment individually. On the initiative of the provincial depot in Noord-Brabant, a shared system called the ‘Archeodepot’ was created (www.archeodepot.nl) (figure 6). Eight provinces and DANS work together in this initiative to provide a single counter for commercial units to upload their SIBK0102 documents prior to depositing their finds and (digital) documentation. Together, they have the necessary critical mass and have succeeded in providing a working system.
- Municipality depots are smaller than the provincial depots and are currently very reluctant to implement the SIKB0102 protocol at all. They are waiting for a (financial) opportunity to create the tools for themselves or to join the Archeodepot.
- Only a few software developers in the Netherlands produce an archaeological (excavation) documentation tool that can create the exchange document. These packages can be bought off the shelf by commercial units, but often at a relatively high cost or with the need for major changes to their daily archaeological practices.

It appears that the expertise required to implement the SIB0102 protocol in its current form is simply too high for the average archaeologist. They must therefore leave this to a few digital experts and start viewing the SIKB0102 document as a black box that is difficult to create and to read. Some organizations prefer not to use the protocol at all (“we just ignore it, until we are forced to use it”) or rely on the occasional (almost) free tools that are made available.

After paying a yearly financial contribution, the SIKB provides access to a validation tool. This enables organizations to check the structure and content of the XML document before sending it to the Archeodepot. This validator prevents many mistakes such as the use of the wrong enumeration version, incorrect tag order, or missing UUIDs. However, the tool also creates (technical) error messages that the average archaeologist finds difficult to understand.

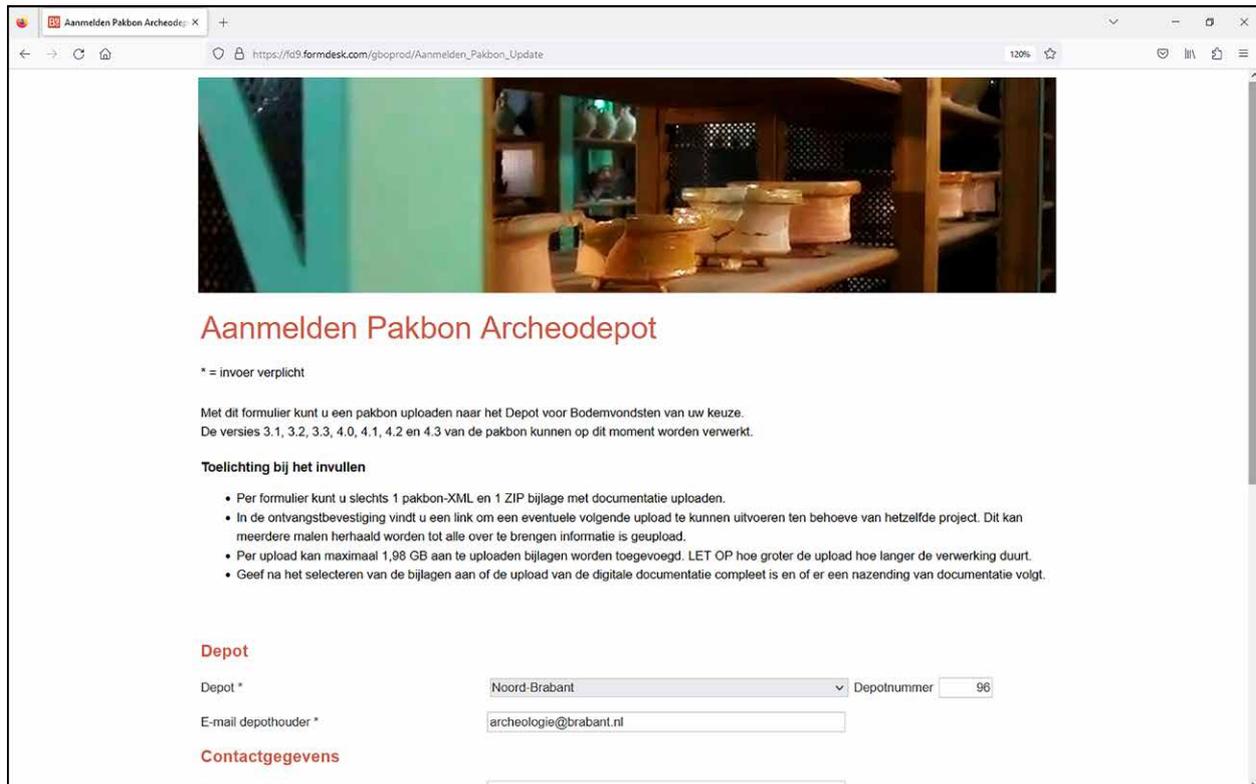


Figure 6: The splash screen of the national counter for depositing the SIKB0102 XML exchange documents. This system validates the documentation before it is forwarded to the designated province.

Under the same conditions, the SIKB also provides a reporting tool that converts a valid XML exchange document into an Excel spreadsheet. This visualizes the XML document's content in a number of separate worksheets that reflect the groups of items in the SIKB0102 model. However, this tool is far from complete. Some municipality depots use this tool to view the content, but this has led to complaints that something is missing in the XML document, although in fact the rendering is incomplete. The reporting tool does not come close enough to the way archaeologists are used to working with their (excavation) data.

Altogether, this situation is arguably a dangerous deadlock that could threaten the implementation of the SIKB0102 protocol. The collaborative initiative taken by the eight provincial depots has probably prevented the Dutch SIKB0102 from suffering the same fate as the UK's FISH Toolkit. Still, many improvements are needed to make the SIKB0102 a real success. Many more actors in Dutch archaeology, such as material specialists and municipality depots, need to board this train in the near future.

5 POSSIBLE SOLUTIONS

If the SIKB0102 document had a simple (albeit arbitrary) hierarchical structure, some of the discussions would probably have been easier. Any web browser would have been sufficient to interactively render the XML into a readable document for humans, providing a solution with a very low threshold. However, making fundamental modifications to the XML structure now seems out of the question. We have already passed a point of no return, given that too many large organizations have already implemented the document. And in any case, this discussion might not be beneficial at all, as the object-oriented data model does have the flexibility to store and share the complexity of the archaeological data (Boasson and Visser 2017). We must therefore consider other options. Here we suggest some possible improvements.

The documentation provided by the SIKB about the protocol is sufficient (UML, XSD, example files) from a technician's point of view. For the average archaeologist, who is usually not really interested in an Entity-Relation model of the database, let alone a UML

The SIKB0102 XML document is a simple text file. That means that in principle it can be opened in any text processing software, from a web browser, a simple Windows Notepad or Wordpad, through an advanced text editor such as NotePad++, to more specialised XML editors like XMLSpy or XmlNotepad. Some software is better suited for reading large XML files and rendering the XML elements in a user-friendly way than others.

An XML element always consists of a start tag `<>` and an end tag `</>`, like one of the first elements in the SIKB0102 document that stores the name of the project:

```
<sikb:projectnaam>Oegstgeest – Nieuw Rhijngest-Zuid</sikb:projectnaam>
```

The starting tag can have additional attributes, for instance for identification, and tags can be grouped (nested) within other tags, as in the following example with a few attributes of a drawing in the SIKB0102 structure.

```
<sikb:tekening bronId="OEGR12_T051" sikb:id="a2012515-e902-4360-9e6c-85e8a53f1aa6">
  <sikb:naam>Detail Coupe 445</sikb:naam>
  <sikb:tekeningtype>DET</sikb:tekeningtype>
  <sikb:tekeningmateriaal>houtvrij mm papier</sikb:tekeningmateriaal>
</sikb:tekening>
```

Sometimes the content between the start and end tag is free text; sometimes it is restricted to one of the prescribed values (enumerations). The allowed values for the type of drawing can be found at codes.sikb.nl, where DET stands for a "detail drawing".



RESTAURA 100 MM

To find the box with this special find from the early Medieval excavation at Oegstgeest in the *pakbon*, follow the following steps:

- Open the XML file in your browser (or text editor of choice)
- Use edit – find (Ctrl+F) or equivalent to search for: “zilveren schaal” (silver bowl)

```
<sikb:vondst bronId="OEGR12_V002.001" sikb:id="575ba625-69a4-4149-8b70-34cb3b9ff585">
  <sikb:naam>zilveren schaal</sikb:naam>
  <sikb:veldvondstId>906d115d-a7b3-44a3-b4e2-10e696030e16</sikb:veldvondstId>
  <sikb:aantal>1</sikb:aantal>
  <sikb:materiaalcategorie>MAG</sikb:materiaalcategorie>
  <sikb:beginperiode>MEVB</sikb:beginperiode>
  <sikb:eindperiode>MEVB</sikb:eindperiode>
  <sikb:exposabel>>true</sikb:exposabel>
  <sikb:verpakkingseenheidId>c9f95c57-2c29-41d9-8dde-d44804ba6d49</sikb:verpakkingseenheidId>
</sikb:vondst>
```

The original find number of the excavator is documented in the attribute `bronId` as part of the `sikb:vondst` tag, while the context of the find is recorded in the `sikb:veldvondstId` tag and the storage location is stated in the `sikb:verpakkingseenheidId` tag, both with their own UUID.

- Copy the UUID from the `verpakkingseenheidId` tag
- Perform a new search throughout the entire document with that UUID

This will provide you with the packaging unit (usually the plastic find bag) and its attributes.

```
<sikb:verpakkingseenheid bronId="OEGR12_V002" sikb:id="c9f95c57-2c29-41d9-8dde-d44804ba6d49">
  <sikb:naam>OEGR12_V002</sikb:naam>
  <sikb:doosId>8f0da90c-7aba-4a7d-a8e0-b1881cbce351</sikb:doosId>
</sikb:verpakkingseenheid>
```

- Use the UUID from the `sikb:doosId` tag once more to find the storage box

```
<sikb:doos bronId="OEGR12_D002" sikb:id="8f0da90c-7aba-4a7d-a8e0-b1881cbce351">
  <sikb:naam>OEGR12_D002</sikb:naam>
  <sikb:breekbaar>true</sikb:breekbaar>
</sikb:doos>
```

As can be seen from the above, a small series of simple text find requests can bring up the box of this special find, in this case `OEGR12_D002`, without the need for special software.

(Opposite page and above) Figure 7: Mock-up of a part of a manual that can help non-digital specialists to use and identify items in the SIKB0102 XML document.

document, this doesn't help much. Our first suggestion is therefore, that a clear manual is produced covering the possibilities and limitations of the protocol in simple words: What is actually in the XML, and where can I find it? This would be a manual with a strong

visual component, breaking down the protocol into entities with which archaeologists are familiar, such as boxes-and-finds or features-and-photos (figure 7).

The SIKB reporting tool is not ideal, nor is it free for everyone. Both conditions could be improved if

| bronid | informatie | naam | materiaal | artefacttype | aantal | gewicht | beginperiode | eindperiode | consv. expo. | desel. | verzamelwijze |
|----------------|------------|--------------------------|-----------|--------------|--------|---------|--------------|-------------|--------------|--------|---------------------|
| 232.1.20001243 | | KOL1768.000232.1.2000124 | ODB | BOT.RUND | 1 | 0 | | | | | AANLEG Context Doos |
| 232.1.20001244 | | KOL1768.000232.1.2000124 | ODB | BOT.RUND | 1 | 0 | | | | | AANLEG Context Doos |
| 232.1.20001245 | | KOL1768.000232.1.2000124 | ODB | BOT | 1 | 0 | | | | | AANLEG Context Doos |
| 232.1.20001246 | | KOL1768.000232.1.2000124 | ODB | BOT | 1 | 0 | | | | | AANLEG Context Doos |
| 233.1 | | KOL1768.000233.1 | MPB | XXX | 1 | 3.2 | ROMV | NTL | | | PUNT Context Doos |
| 234.1 | | KOL1768.000234.1 | MPB | XXX | 1 | 7 | BRONSV | NTL | | | PUNT Context Doos |
| 235.1 | | KOL1768.000235.1 | KER | AWG | 1 | 3.6 | MEVA | MELB | | | AANLEG Context Doos |
| 235.2.20001477 | | KOL1768.000235.2.2000147 | ODB | BOT.RUND | 1 | 0 | | | | | AANLEG Context Doos |
| 235.2.20001478 | | KOL1768.000235.2.2000147 | ODB | BOT | 1 | 0 | | | | | AANLEG Context Doos |
| 235.2.20001479 | | KOL1768.000235.2.2000147 | ODB | BOT | 1 | 0 | | | | | AANLEG Context Doos |
| 236.1 | | KOL1768.000236.1 | SXX | XXX | 1 | 6.6 | PALEOV | NTL | | | AANLEG Context Doos |
| 236.2 | | KOL1768.000236.2 | KER | AWG | 1 | 5.3 | MEVA | MELB | | | AANLEG Context Doos |
| 237.1 | plaatje | KOL1768.000237.1 | MPB | XXX | 1 | 6.4 | ROMV | NTL | | | PUNT Context Doos |
| 238.1 | | KOL1768.000238.1 | MPB | XXX | 1 | 0.9 | ROMV | NTL | | | PUNT Context Doos |
| 239.1 | | KOL1768.000239.1 | MPB | XXX | 1 | 1.1 | ROMV | NTL | | | PUNT Context Doos |
| 240.1.20001219 | | KOL1768.000240.1.2000121 | ODB | BOT.RUND | 1 | 0 | | | | | AANLEG Context Doos |
| 240.1.20001220 | | KOL1768.000240.1.2000122 | ODB | BOT | 1 | 0 | | | | | AANLEG Context Doos |

Figure 8: A prototype database (proof of concept) has been created with Microsoft Access. This database imports a pakbon and renders it in several ways through hierarchical forms, in this case starting with the finds.

the SIKB is willing to put in the required effort (in the near future). As a second suggestion, a more full-scale viewer should be developed, one that uses a database instead of a spreadsheet as a basis. Such a database would allow for a user interface that visualizes the entities in a way that is very close to archaeologists' day-to-day practice (figure 8). A database would allow for multiple relationships to be presented (boxes – finds, finds – context, context – photos, photos – files). Such a standardised viewer would probably be very helpful for guiding and streamlining the discussions between employees of the depositor and depot. Any problems could likely be identified (interactively) and solved much more quickly if both parties were using the exact same visualization.

Such a tool should be open-source, cross-platform, freely available to all, and maintained for future releases of the SIKB0102 protocol and database software used. Of course, some (financial) arrangements would need to be established to achieve this goal.

Dutch archaeology contains many small, single-handed companies that carry out small archaeological projects with a limited number of finds, photos and data tables. A small commercial unit might for instance be commissioned to check the archaeological potential of a small area in a private garden with two or three corings. These small-scale projects occur frequently and often have a short turnaround time, minimum dataset and

standardised report. It would probably be very effective to have a tool that directly stores the available data in a small database that exactly mimics the entities in the SIKB0102 protocol. Such a free, open-source data entry tool would probably also serve to educate a much wider group of archaeologists about the content of the XML. It would become simply a matter of “learning by doing”.

A few simple additions could potentially take the SIKB0102 out of the realm of technicians and bring it into the world of many Dutch archaeologists. Where, in our view, priority should be given to the creation of an open-source toolkit to visualize the content of an XML exchange document (option 2).

6 ADDITIONAL BONUS: SIKB0102 AS AN ARCHIVING FORMAT

An XML document is basically a simple text file, with a simple markup structure. Each element has a starting tag (e.g., <project>) and ending tag (</project>). Elements can be nested to as many levels as required, as long as the document remains well formed. The content of an XML document is (should be) documented in an XSD (XML Schema Definition Language) document, which prescribes the tags in great detail, for example: which tag names, in which order, compulsory or not, multiple values allowed or not, with a predefined value (enumeration) or free text. These characteristics make XML a very promising candidate for the long-term archiving of

DANS DATASET DESCRIPTION

The SIKB maintains data exchange protocols for both soil researchers and archaeologists. The protocol for Archaeology (SIKB0102) has been in place since 2011 (*) and has seen many minor and major revisions. The SIKB makes only the most recent versions of the protocol available on its website. The SIKB's view is that the exchange documents are used only once, *i.e.*, at the moment an excavation is finished and the finds and documentation are deposited at one of the provincial or municipality depots.

However, a data exchange document (*'pakbon'*) brings together data about many aspects of an excavation in a highly standardised manner. Although this is probably not as detailed and rich as the original databases and (GIS) files from the excavator, it is and will remain a valuable resource for future archaeologists. The XML documents are stored in the repositories as separate files. In order to understand and reuse such a document, the technical description of the specific version of the protocol should be available at any time. This dataset brings together that metadata, for as many different versions of the *pakbon* as (still) possible.

(*): SIKB 2011, Wijzigingsblad KNA 3.2 Landbodems, Stichting Infrastructuur Kwaliteitsborging Bodembeheer, Gouda.

Figure 9: Dataset description at the DANS EASY repository of the (historic) documentation of the SIKB0102 protocol (doi.org/10.17026/dans-zbn-be94).

digital information. DANS already experimented with this idea in a pilot project called MIXED in 2007 (Van Horik and Roorda 2011). Once digital information is converted to a well-documented XML file, it does not need much attention to be readable and understandable in, say, 20 years' time.

Some archaeological units have been experimenting with and using the SIKB0102 protocol for quite some time now, and their number is increasing rapidly as a result of provincial repositories requesting the protocol. The SIKB0102 specifications are updated yearly. This entails not only minor alterations in response to (for instance) changes in the municipalities, new commercial units, or improvements to the protocol, but also more fundamental changes to the structure of the document. Branches have been renamed, replaced, added, and removed from the protocol, *e.g.*, when specific information is no longer relevant (like many Archis 2 attributes). The SIKB publishes the protocol on its website, along with the XSD, enumerations and examples (www.sikb.nl/datastandaarden/richtlijnen/sikb0102). Any changes between versions are documented in a separate report.

The SIKB is convinced that the purpose of the data exchange document is limited to a single-use event: at the closing stages of a research project, at the moment a commercial unit sends the XML document to the designed depot in the province (or

municipality). The depot imports the data, and the lifespan of the XML document is over. Preferably, both parties should be using the current, in-force version of the protocol. But because software updates can easily lag behind, a few older versions of the protocol are still supported and available on the SIKB website. Currently (as of May 2023) only the previous version (4.3) and the current version (4.4) are available. The data model (UML), XSD, enumerations (*domeintabellen*) and examples can be downloaded. The thesauri (enumerations) are also published on a separate website (codes.sikb.nl), for the current version of the protocol.

In Dutch archaeology, the XML document is accepted at the repositories of the provincial depots, as well as by DANS and Archis, among others. These repositories not only convert the content of the *pakbon* into their own management system, but also store the *pakbon* for the long run. As this XML document holds the majority of a project's produced archaeological data, it is a valuable resource in its own right. The data may not be as detailed and rich as the original data files from the commercial unit, but they hold the information in a highly standardised manner. Suppose that we could bring together all these XML documents produced over the past five years. This would allow for a very useful and smart search engine to cross-search harmonised archaeological projects on a national scale.

Synthesizing information at that scale of detail is impossible in any of the current repositories. Several examples of such a ‘big data’ approach, such as text mining (Brandsen 2022; Fischer *et al.* 2021) and data mining (Wilcke 2022), have recently produced promising results in Dutch archaeology.

However, one essential condition for using SIKB0102 as an archiving format is missing: the XSD and enumerations should be available for any possible version of the exchange format. Unfortunately, the SIKB currently fails to make these available. We feel that this is a crucial missed opportunity. We lack the UML and especially the XSD of the previous versions. A provisional dataset (figure 9) has recently been created at DANS (DOI:10.17026/dans-zbn-be94); this holds the documentation of as many previous versions of the protocol that could still be gathered from the SIKB website and local copies by the authors.

XML as an archiving format was also recently proposed by Brandsen (2022) in his Ph.D. thesis on text mining archaeological reports. Since the Malta legislation entered into force, these grey literature reports have been produced by commercial units in such large numbers that it has become very difficult to keep up with all new discoveries. A special grant scheme, the ‘Oogst van Malta’ (Malta harvest), also addresses this problem, enabling archaeologist to dedicate their time to special topics, in order to translate the information from these separate reports into a coherent archaeological narrative. One of the problems Brandsen encountered is the long-term archiving format used by the repositories. The PDF format is very difficult to re-engineer into text. Drawing distinctions between different elements of the publication – such as text body, captions, chapters, paragraphs, table content, and so on – is almost impossible. For text mining, understanding the structure of the document is paramount, as the flint arrowhead described in a chapter called ‘Neolithic period’ is implicitly dated. The best possible solution would be storing archaeological publications in a generic XML format that incorporates the document’s hierarchical structure, thereby making explicit what we as human readers can deduce immediately. From an archiving standpoint, the XML format is also preferred to the PDF/A (Adobe-specific) format. Although this would be a major step forward, PDF will probably remain the de facto standard worldwide for some years. Still, we could consider asking the SIKB to add some of the content (*e.g.*, the summary) of the report to the data exchange format SIKB0102.

When archiving is designated as one of the functions of the SIKB0102 protocol, an additional incentive to use the protocol’s spatial components is also needed, as this seems to be used very rarely at present. Enabling even a fuller use with, for instance, the location of trenches, finds and excavated features.

7 CONCLUSIONS

It goes almost without saying that Dutch archaeology is in need of a standardised exchange protocol, especially now that almost all archaeological partners collect archaeological documentation digitally under the Malta trajectory. The SIKB0102 protocol already fulfils a key role, although not all archaeologists are comfortable with the chosen format. It is important that all partners are convinced of the benefits and are provided with a series of low-threshold tools. While the *pakbon* was originally designed to improve the transition between the excavator and the legal owner of the finds and documentation, SIKB0102 has the potential to become a versatile, flexible and universal exchange and archiving format for a highly standardised set of archaeological data.

The data exchange protocol SIKB0102 was almost exclusively designed by a group of (heavily) ICT-trained archaeologists. The SIKB seems to have misjudged the gap in interests and skills between the ‘average’ archaeologist and the ‘computer’ archaeologist. The deposit process has not become easier for those who have to do this on a daily basis in accordance with the KNA regulations. Many archaeologists and personnel at the depots still consider the *pakbon* a complex and difficult black box and are still reluctant to introduce the protocol at all. The problems that occur in the handover cannot yet be solved easily. Both parties need to have a shared knowledge base and easily available tools in order to discuss problems and find solutions to discrepancies.

We feel that the most important next step is improving the availability of open-source additions to the “SIKB Interoperability Toolkit”. Some simple additions would equip archaeologists with tools to really explore the data that they currently experience as being hidden inside the *pakbon*. Within a (geo) graphical user interface, they could view the data, see links between entities, and (most importantly) share a common dashboard via which different parties can solve problems. Only with tools like this can archaeologists experience the benefits of a protocol such as the SIKB0102. We would like to see the SIKB and/or RCE initiate such a development together with the Dutch archaeological community. Creating and maintaining

these open-source tools should be a joint effort from all actors in the Dutch archaeological field, because all of us would benefit. The tools should not only facilitate the deposit process today, but also create valuable standardised descriptions in XML that could serve as a resource of archaeological information for the future.

REFERENCES

- Boasson, W. and R. Visser. 2017. "SIKB0102: Synchronizing Excavation Data for Preservation and Re-Use." *Studies in Digital Heritage* 1, no. 2: 206-224. DOI: 10.14434/sdh.v1i2.23262.
- Boogert, S.J. 2006. *Wie wat bewaart, die heeft wat: een onderzoek naar de overdracht van archeologische vondstcomplexen aan provinciale depots*. Den Haag: Erfgoedinspectie / Archeologie.
- Brandsen, A. 2022. "Digging in documents: using text mining to access the hidden knowledge in Dutch archaeological excavation reports." PhD diss., Leiden University. <https://hdl.handle.net/1887/3274287>.
- Erfgoedinspectie. 2018. "Verder graven in depots: behoud en toegankelijkheid in gemeentelijke archeologische depots." Den Haag: Erfgoedinspectie, Ministerie van Onderwijs, Cultuur en Wetenschap.
- Fischer, A.D., H. van Londen, A.L. Blonk-van den Bercken, R.M. Visser, and J. Renes. 2021. "Urban farming and ruralisation in the Netherlands (1250 up to the nineteenth century), unravelling farming practice and the use of (open) space by synthesising archaeological reports using text mining." Amersfoort: Cultural Heritage Agency of the Netherlands (Nederlandse Archeologische Rapporten 68).
- Gilman, P. and M. Newman. 2007. "Data standards for the Historic Environment, part of Informing the Future of the Past, Guidelines for the Historic Environment Records, Archaeology Data Service." Wiki, Electronic Document. Accessed June 12, 2021 <https://archaeologydataservice.ac.uk/ifp/Wiki.jsp?page=SectionB.7>.
- Meffert, M. 2018. "De pakbon voorbij: de impact van digitaal werken in de Archeologie." Presentation at SIKB jaarcongres 2018, De verbindende kracht van data. Electronic Document. Accessed June 12, 2021. https://www.sikb.nl/doc/congres2018/presentaties/sessie1_1_PakbonVoorbij_MartinMeffert.pdf.
- SIKB. 2011. "Wijzigingsblad KNA 3.2 landbodems. Gouda: Stichting Infrastructuur Kwaliteitsborging Bodembeheer." Electronic Document. Accessed June 12, 2021. https://www.sikb.nl/doc/KNA32/Wijzigingsblad_KNA_3.2_landbodems_12_december_2011.pdf.
- Sueur, C., J.W.H.P. Verhagen, and M. Wansleeben. 2008. "Advies archeologische uitwisselingsprotocollen SIKB." Amersfoort: Vestigia BV (Vestigia-rapport V513).
- Van Horik, R. and D. Roorda. 2011. "Migration to Intermediate XML for Electronic Data (MIXED): Repository of Durable File Format Conversions." *The International Journal of Digital Curation* 6, no. 2: 245-252. DOI: 10.2218/ijdc.v6i2.200.
- Verhagen, J.W.H.P., M. Wansleeben, and C. Sueur. 2011. "Setting a Standard for the Exchange of Archaeological Data in the Netherlands." In *On the Road to Reconstructing the Past: Computer Applications and Quantitative Methods in Archaeology. Proceedings of the 36th International Conference, Budapest, April 2-6, 2008*, edited by E. Jerem, F. Redö, and V. Szeverényi, 152-155. Budapest: Archaeolingua.
- Wilcke, W-E. X. 2022. "Machine Learning on Multimodal Knowledge Graphs: Opportunities, Challenges, and Methods for Learning on Real-World Heterogeneous and Spatially-Oriented Knowledge." PhD diss., Vrije Universiteit Amsterdam.

Digital Data Integration in Mediterranean Field Survey Archaeology: Status Quo and Future Perspectives

Tymon de Haas and Martijn van Leusen

1 BACKGROUND

Let us begin by recalling that, although personal computers were introduced in the 1970s, their use in both the nascent commercial archaeology sector and in academic archaeology was limited to a few pioneers – who founded the Computer Applications and Quantitative Methods in Archaeology conference in 1973 – until about the mid-1980s. Since then, most of our tools for data collection have grown electronic brains and digital outputs, so if digital archaeological data is perhaps not currently growing at an exponential rate, it certainly has done so over much of this 35-year period. Needless to say, in the context of this volume, the challenges of managing, preserving and analysing such vast amounts of digital data are by now formidable.

We can sketch a more specific picture for the subdiscipline with which we are most familiar: that of archaeological fieldwalking. In its modern systematic (though not yet intensive) form, this dates to the 1960s (Alcock 2000; Alcock and Cherry 2004; Attema *et al.* 2020) and involves the collection of repeated observations of archaeological sites, off-site distributions, and individual artefacts over space. Its systematic character lends itself to documentation in the form of relational databases (available in desktop form since the early 1980s) and maps (digitized in GIS formats since the early 1990s, but coming into their own only with the introduction of GPS-based digital field mapping around 2000; see also Van Leusen 2001; Gillings 2001). It is perhaps surprising that no further substantial technological progress has been made since then in the management of survey data, but that is not our main current stumbling block for integrating survey data. It is instead the lack of standardization in the way we have been documenting our surveys. This affects both current and legacy survey datasets, and is a matter of concern when considering the design of future survey projects.

The purpose of fieldwalking surveys in general is the reconstruction of the Braudelian 'history of the medium term' of the region or the site of interest; with rare exceptions, surveys are multiperiod and try to achieve a high spatial resolution, such that only the very smallest sites could escape attention. Survey data should therefore find good use as ammunition in historical debates and for many of the 'grand challenges' defined by Kintigh and colleagues in *American Antiquity* in 2014. In particular, they state: "Addressing many of these challenges will require both sophisticated modelling and large-scale synthetic research that are only now becoming possible. Although new archaeological fieldwork will be essential, the greatest pay off will derive from investments that provide sophisticated research access to the explosion in systematically collected archaeological data that has occurred over the last several decades" (Kintigh *et al.* 2014, 5). Sophisticated research access, in our view, means that data must be made accessible in its full breadth and detail in order to exploit its comparative potential to the fullest.

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A key challenge for Mediterranean survey archaeology thus concerns the discrepancy between the spatial scale at which individual projects are run, and that needed to address these grand challenges. The greater part of Mediterranean survey data is about the classical world, and has the potential to contribute to (if not actually to lead to the revision of) historical debates that currently disregard this data source, such as that regarding the nature of the Roman economy (see section 2). Finding support for such highly debated characteristics as the level of market integration and growth requires the marshalling of data at spatial scales well beyond those of individual field survey programs, and therefore the integration of multiple datasets. As noted above, the lack of standardization of existing (legacy) survey datasets currently forms a major obstacle in addressing such grand challenges.

However, the problem goes deeper, as the track record of Mediterranean field survey in proper publication, documentation and archiving is far from satisfactory. From an ethical point of view – and here we can easily link to the well-known FAIR criteria for data archiving and reuse as a standard-to-be-achieved (Wilkinson *et al.* 2016)¹ – it is indefensible to produce survey data that cannot be accessed and fully re-used by others. The FAIR ‘guiding principles’ require scientific data to be not only findable, accessible and interoperable, but also re-usable – and this latter criterion requires much higher standards of data documentation than are currently achieved even in state-of-the-art data archives.

These shortcomings should provide sufficient arguments to overcome any reluctance archaeologists might feel to standardize survey data collection and documentation methods. But even if this were achieved, it would only affect future data collection, not the huge amounts of ‘legacy’ survey data that have been produced over the past 50 years. For that, we will need to overcome a series of conceptual and technical hurdles to the integration of existing datasets, as further detailed below. In what follows, we discuss the issue of survey data integration in more detail. We will focus on the countries bordering the northern Mediterranean, for two reasons. First, the recent review by Attema *et al.* (2020) helps capture the variability of survey approaches within this region, from survey design to recording practices. And second, the authors have long been working as survey

archaeologists in this region and have been studying the twin problems of survey data archiving and integration for central Italy over the past decade.

Our contribution aims to analyse the current obstacles to such integration and provide recommendations to move towards making survey data sustainable and re-usable. We reiterate that this should be viewed within a much broader context of increasing awareness of the need to integrate archaeological datasets, see for example the English Landscape and Identities project and activities of the CAA Special Interest Group Data Dragons (Cooper and Greene 2015; McCoy 2017).²

2 CURRENT APPROACHES TO DATA INTEGRATION IN MEDITERRANEAN SURVEY ARCHAEOLOGY

Data integration is a particularly important and challenging theme within Mediterranean survey archaeology. Since the first systematic field survey projects were launched in the 1950s, hundreds of survey datasets have been compiled, nearly all of which cover comparatively modest study areas – typically, the hinterland of a single ancient town or a single watershed basin (figure 1). Despite their large number, the spatial coverage of these uncoordinated studies therefore remains extremely patchy; in effect, they are more suited to address research questions of local interest than the broad questions highlighted by Kintigh and colleagues. The latter were tackled more successfully in regions such as Meso-America, where research areas are larger and a higher degree of standardization has been achieved (Blanton 2001; Fentress 2000; Terrenato 2004). Moreover, with this relatively young field of research having matured rapidly in recent decades, survey project designs and methods vary greatly. In general terms, we may distinguish between intensive, extensive, and topographic surveys: while the former applies intensive sampling strategies to collect and document artefacts from both sites and off-site contexts, extensive surveys focus primarily on the detection and characterization of sites (with limited collection of artefacts), and topographic surveys focus on the description of architectural remains on the larger and better-preserved sites only. Consequently, the kinds of information collected in these different types of surveys – and by extension the structure and content of the databases they generate – varies as well.

1 <https://www.force11.org/fairprinciples>.

2 <https://datadragon.link/>.

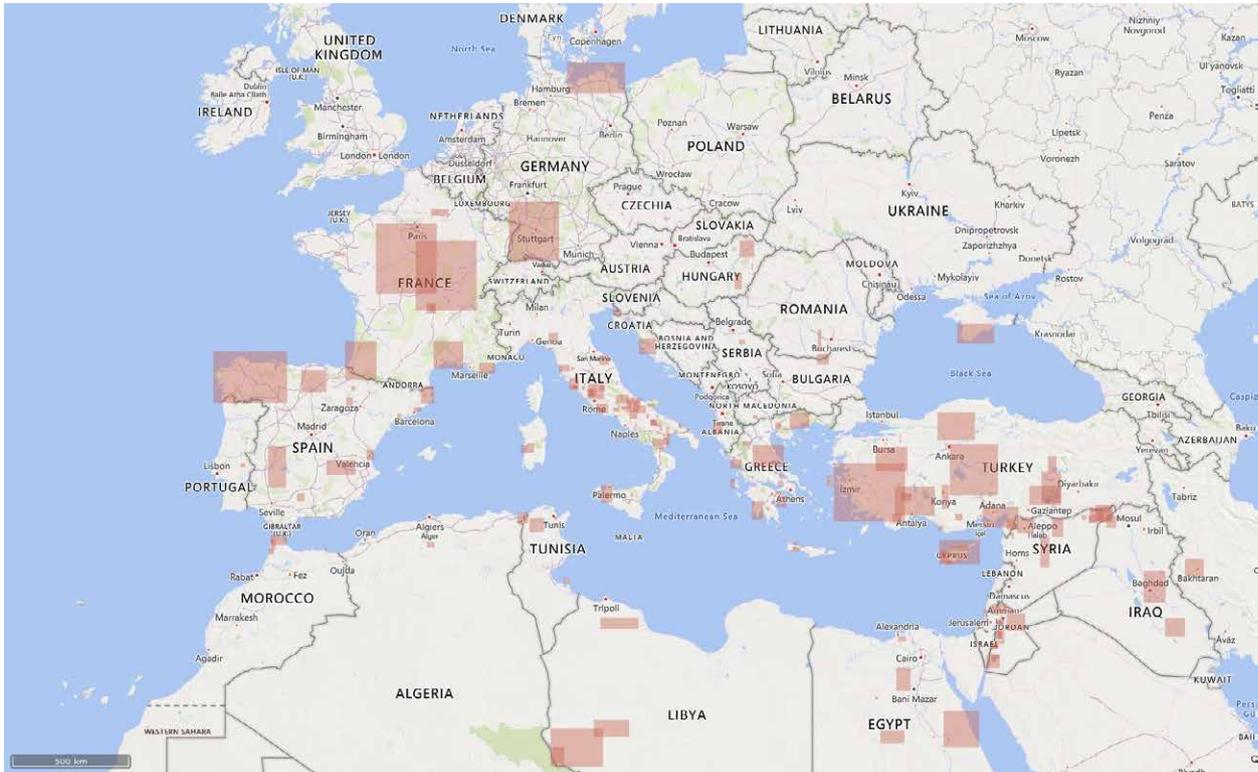


Figure 1: Surveys in the Mediterranean area, data from Fasti Online Survey (<https://www.fastionline.org/survey/>).

Recent attempts at establishing best practices (Attema *et al.* 2020; Witcher 2006a), while helpful in mitigating the problem of integrating future survey datasets, do not address the need to retrospectively integrate the massive numbers of legacy datasets generated in this manner. The challenges of integration therefore remain considerable. We will illustrate this by reviewing four ways in which scholars have attempted to integrate multiple regional survey datasets. These have been applied with different aims in mind and therefore require different levels of engagement with the (digital) data themselves.

The first approach is that of ‘narrative’ integration, in which multiple published survey datasets are drawn on without any attempt to access the underlying data. This approach has developed as a response to the various issues involved in comparing data referred to in section 1: because formal integration is deemed too complex or even impossible, scholars have focused on comparing and integrating the *interpretations* of the data. A typical example of this approach can be found in the ancient historian Luuk de Ligt’s work on the demography of Roman Italy (De Ligt 2012, chapter 6).

Fierce debates have raged around the two main, and quite divergent, demographic reconstructions commonly referred to as the high and low count for the rural population of the Roman Empire between the 2nd century BC and the 1st century AD. Following an extensive discussion of the methodological differences between the various topographic, extensive, and intensive surveys in central and southern Italy, De Ligt concluded that comparisons can be drawn only on the basis of the settlement trends reported by the different projects, with obvious consequences for the reliability of these comparisons (De Ligt 2012, 257). Another example stems from the Regional Pathways to Complexity project (Attema *et al.* 2010), which aimed to compare developments in rural settlement and land use by indigenous societies in the context of processes of urbanization and (Greek and Roman) colonization in south-central Italy. The integration and comparison of field survey datasets from three regions was at the core of this project, but the data turned out to be too heterogeneous (Attema *et al.* 2010, 24), and the actual comparisons therefore drew on their interpretation only.

A second approach may be dubbed ‘metadata integration’. This approach aims not to integrate survey datasets to address specific research questions, but rather to provide information on the characteristics of Mediterranean survey datasets and point to the location where the associated data can be retrieved. This approach was pioneered by the MAGIS database (Foss and Schindler 2008), which collated extensive information on 382 circum-Mediterranean survey projects, including metadata on geography, project staff, spatial and chronological coverage, methodology, specialist studies, environmental parameters, and bibliographic references. While work on the MAGIS database has been discontinued since 2011, it formed the basis for Fasti Online Survey, a website and associated database developed by the Royal Netherlands Institute in Rome and the International Association for Classical Archaeology (AIAC; www.fastionline.org/survey). Although only some of the metadata present in MAGIS can be consulted in FASTI Online Survey, it does provide a geospatial interface and the possibility to up- and download survey datasets, such as GIS map layers. At the same time, there are no set criteria for the metadata documentation to be submitted with these files, and so far no projects have submitted their full digital documentation to this platform. A third, independent platform launched in 2020 by a mainly US-based group of archaeologists, www.fieldwalker.org, also provides a geospatial interface to circa 650 survey projects and associated metadata, with links to open-access data archives held elsewhere. These ‘archives’, available for only 33 of the 650 projects, range from fully documented archives stored in repositories to simple project websites or PDFs of project publications. While such online facilities provide a useful starting point for those interested in integration of survey data, they neither provide actual integrated survey data nor require the project PI to supply specific metadata or standardized documentation. It therefore remains up to the user to explore to what extent they can actually integrate and re-use them.

A third approach is ‘question-specific’ integration, where the aim is not to integrate complete (digital) survey datasets, but rather to select certain data elements in order to answer specific research questions. This kind of integration can be traced to the early 1990s and focuses on the Greco-Roman world: we might think of the well-known study of the impact of Roman conquest on the rural landscapes of Greece by Susan Alcock (1993), Bintliff’s (1997) and Stone’s (2004) analyses of settlement trends from surveys

in ancient Greece and modern Tunisia, Witcher’s (2006b) and Launaro’s (2011) comparison of diachronic changes in Roman site numbers in Etruria and Italy, respectively, and Samuels’ (2019) integration of site data from c. 20 central Italian surveys in order to trace early Roman non-elite behaviour in the countryside. The “Changing the face of the Mediterranean” project (Palmisano *et al.* 2018) presents a rare recent example of integration with a broader scope, employing settlement data from 59 surveys in central Tyrrhenian Italy in order to evaluate demographic change from c. 8000 BC to AD 500.

These examples share a focus on the site data produced by survey projects, ignoring any off-site and object data that might be available. But even in the integration of site data we are faced with the fact that individual projects have employed different site typologies and different periodization systems. These data must therefore be reclassified using a simplified typology (*e.g.*, the ‘farm-villa-village triad’) and chronology, consequently allowing only very broad trends over time to be identified. Issues of methodological comparability between the projects that created the different underlying datasets (*e.g.*, regarding intensity of surveying, site definition criteria, approaches to site dating) tend to be acknowledged but remain unresolved. For example, Alcock (1993) distinguished between intensive and extensive surveys, and Palmisano and colleagues (2018) recorded the spatial precision of the site location and the reliability of the site size estimate, but not the overall intensity of the surveys (see also Van Leusen 2002, chapter 4).

Technically, this kind of integration only requires a reclassified and/or reinterpreted version of the original data to be brought together in a simple database or spreadsheet for basic quantification (*e.g.*, generating settlement trend diagrams; Palmisano 2018). While useful for addressing specific research questions, this integration therefore does not offer much scope for broader or deeper analysis beyond settlement trends.

A fourth (and much more labour-intensive) approach to data integration we might call ‘data merging’. Unlike the previous type of integration, this aims to integrate source datasets fully by bringing them together into a single integrated database schema, thus allowing for a wide range of site- and object-based comparative analyses. We know of only one example: our own Roman Hinterland Project (RHP; <https://comparativesurveyarchaeology.org/>), which integrates three major survey datasets from

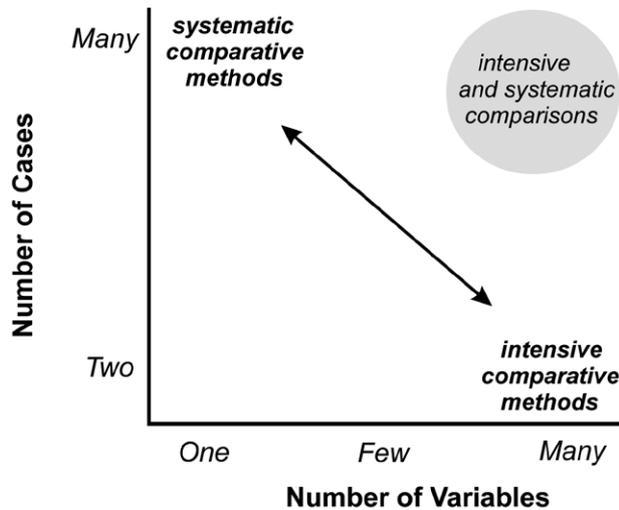


Figure 2: Intensive and systematic comparative strategies, after Smith and Peregrine 2012, fig. 2.1.

the surroundings of Rome in order to develop new interpretations and narratives of the impact of Rome on surrounding towns and territories. To this end, the RHP ‘maps’ site, off-site, and object data from the three source datasets and imports them into a database designed to allow a wide range of spatial, temporal, and typological queries. For example, in Attema *et al.* (2021) regional differences in the distribution of transport amphorae and fine wares were explored that inform us about degrees and patterns of integration of rural communities in regional economic networks and the wider imperial economy. The project also aims to add more survey datasets from other parts of the Mediterranean in due course.

While offering many more analytical possibilities, this approach also comes with great challenges. As in the ‘question-specific’ approach to integration, we must deal with the heterogeneity of the input classifications and chronologies. However, this is now no longer just about site attributes but includes various artefact classifications and ceramics typologies, each with associated chronologies. A further important characteristic of this integration project is that it maintains, in addition to the integrated database, the underlying source datasets, so that both project-specific classifications *and* overarching simplified classifications can be exploited.

In addition to the integration of classification systems, this approach requires an analysis of the underlying methodological and conceptual differences between the source datasets. If one is only interested

in comparing site trends, it is enough to know that sites have broadly been located, defined, and dated in a comparable manner across projects. However, meaningfully integrating and comparing the artefact assemblages from those sites will also require close scrutiny of the sampling strategies employed in these projects. This involves an intensive and time-consuming review of both the data and the methods with the various data owners, as well as the development of complex mechanisms to filter the original datasets.

3 DISCUSSION

As we have seen, even if some of these approaches have analytical potential, all of them have significant limitations and drawbacks. It is instructive to compare them using Smith and Peregrine’s (2012) framework, distinguishing between ‘systematic’ comparisons that usually draw on statistical analyses to compare many cases using only one or a few variables, and ‘intensive’ methods that compare only a few cases but do so for many variables (see figure 2). Our first, ‘narrative’ approach can then be put in the ‘intensive’ corner of the diagram: comparing few cases, it can accommodate an extensive contextual evaluation of these cases but cannot provide any formal statistical support for its conclusions. Our second approach, ‘metadata’ integration as pursued by Fasti Online Survey and MAGIS, paves the way for the third approach, ‘question-specific’ systematic, statistical comparison of a few variables such as site density for many cases, and both can be put in the top left hand corner of the diagram.³ All three are confined to the main systematic-intensive axis of the diagram, whereas in our view, the analysis of survey datasets should ideally take place in the top right-hand corner of the diagram, allowing comparisons that are both intensive *and* systematic, using many cases *and* many variables. This is achieved by the fourth, ‘data merger’ approach, as

3 A potential issue with platforms such as MAGIS, Fieldwalker, and Fasti is the limited sustainability of such digital tools. The former two depend(ed) on efforts and investments by individual scholars and institutions, which means there is little guarantee they will be maintained in the long run. Fasti Online forms part of the well-established international association of classical archaeologists (AIAC) and will thus be somewhat less vulnerable, but it, too, is dependent on continued AIAC support.

exemplified by the RHP, as it allows the quantitative and comparative analysis, both synchronic and diachronic, of multiple variables across hundreds of sites (Attema *et al.* 2021).

However, as already intimated in section 2, this approach has proved to be both technically and conceptually challenging. Creating data schemes, classifications and chronologies compatible with multiple source datasets requires a substantial investment, even when, as in our case, those datasets were collected with roughly similar strategies and cover adjacent areas with similar traditions of material culture. Imagine what would be required to successfully achieve this kind of intensive data merger with not three but, say, three *hundred* datasets, from historically and archaeologically diverse regions across the Mediterranean, which may also be more diverse in terms of research methodologies! Data merging may therefore be a sustainable approach for dealing with existing datasets in the short to medium term, but it is not likely to be so in the longer term.

What, then, are our options to increase the scope of survey data integration? Here we come to a fifth approach to data integration, which is potentially more sustainable but as yet underexplored, combining semantic modelling and Linked Open Data (LOD).⁴ The former makes explicit the meaning of the concepts used in a dataset; the latter makes distributed online data accessible in a queryable format. The two together enable the eventual integration of distributed datasets, complying with all four criteria in the FAIR guidelines. This kind of digital data integration relies on the description of individual datasets by their owners according to an agreed set of concepts, and the subsequent publication of these datasets according to an agreed protocol. As we have argued in more detail elsewhere (De Haas and Van Leusen 2020, with references), the CIDOC CRM ontology provides a semantic model that is relatively stable and well developed, and that has already been applied successfully in the integration of other kinds of archaeological data. This approach has not yet been applied to field survey data,

but we have extended the CIDOC CRM ontology with concepts relevant for field surveying (<https://zenodo.org/record/7863486#.ZEfbcOxBzhk>) and are building a mapper in order to allow the creation of Linked Open Survey Data.

Whether we opt for the data-merger approach or the LOD approach, in-depth data integration requires archaeologists to not only make their datasets available to others, but also to be much more explicit about the nature and limitations of their data. As we have discussed in section 1, there is a need for much higher documentation and archiving standards in order to make datasets FAIR (De Haas and Van Leusen 2020). Platforms such as Fasti Online Survey contribute to making important legacy datasets findable and accessible, but enforce no rules as to the documentation of data or the formats in which they are provided, and hence do not guarantee interoperability and re-usability. Moreover, a review of Fasti, fieldwalker.org and the digital data archives DANS and ADS shows that only very few (perhaps a dozen) projects have archived any data to date. Apparently, few researchers are both aware of the need to document and archive their data, and sufficiently motivated to do so. Why is this?

Several – related – factors may explain why documentation and archiving of survey data have remained underdeveloped so far. One is that many legacy survey project leaders (legacy data owners) belong to a generation that grew up at a time when survey was not regarded as a serious research activity, long-term accessibility of archives was not yet an issue, and there was little or no digital infrastructure. Perhaps these older scholars are also less willing to share, realizing that they are responsible for very large amounts of (often heterogeneous) data accumulated over decades of research: its full documentation would be a formidable and costly challenge. More generally, documenting, publishing, and archiving datasets is not considered as sexy as field research or publication of analytical results, and receives little academic recognition: data archives are not a regular feature of scholarly CVs, and do not figure highly in universities' output measurement.

A second factor is the availability of appropriate resources. Many senior academics have little affinity with the fast-changing world of digital data and the requirements for proper digital archiving. While dedicated support staff within archaeology departments could in theory provide the research staff with the requisite technical know-how, their

4 The ARIADNE project, funded from 2013 by the European Commission (<http://www.ariadne-eu.org>), and its cloud-based data infrastructure extension ARIADNEplus (<https://ariadne-infrastructure.eu/>; running until 2023) are working towards similar goals. A very recent publication by Collins-Elliott (2022) provides the first example of the use of semantic modelling to integrate legacy surveys.

priorities tend to lie elsewhere and ICT support remains project-based rather than permanent. Externally funded research has the same drawback: nearly all academic research is nowadays funded by national or international bodies such as the ERC or, in the Netherlands, NWO. These do have requirements regarding data documentation, archiving, and, increasingly, Open Science, and researchers can reserve budget for this, but data management is then usually left to a student assistant or Ph.D. student. In this situation, universities will not make any structural investment in (support staff for) archiving, and any expertise built up by project staff is lost again at the project's conclusion.

The third and final factor concerns the lack of archiving standards. Up until the beginning of this century, funding bodies, universities, and heritage management authorities had little if any guidelines for data documentation. In the course of the implementation of the Valletta Treaty and with the advent of commercial rescue archaeology, national standards for recording and documentation practices have been developed. However, at least for the Netherlands these do not cover field surveying (SIKB n.d.) and are insufficiently ambitious. Repositories such as ADS in the UK and DANS in the Netherlands do have concrete guidelines, but depositing digital data archives is often not obligatory when the research is undertaken in another country, which is the case for many survey projects in the Mediterranean that are carried out by universities from countries like the Netherlands, the UK, and the US. Moreover, because the repositories do not require explicit documentation of concepts and procedures, those guidelines are still no guarantee that datasets can be re-used and integrated.

So, we are facing two challenges: first, many survey data have not been documented and archived at all; and second, datasets that have been documented and archived still do not fulfil the minimum/FAIR requirements for integration and re-use. We might consider different ways to tackle the first challenge. First, researchers' motivation to archive digital data should be intrinsic – researchers feel a moral obligation – but that would require a profound change in their attitudes. A significant incentive might come from a greater appreciation, both academically and in research assessments, for well-documented data publications. Better – and structural – (technical) support for archiving would be another stimulus, organized either decentrally (at the level of an archaeological institute), or centrally

at data repositories. We might also consider whether the documentation and publication of data should be enforced more strictly by funding bodies ('you will not receive new funding until your previous project has been deposited') and government bodies ('you will not receive a new permit until your data have been deposited'), but this would affect only current and future survey projects. For legacy datasets, a redirection of research funding may be the only way to substantially increase the number of documented and archived datasets.

The second challenge, bringing the standards of archived data documentation up to the desired level, is equally difficult. This is partly because national data repositories, heritage management authorities, and funding bodies all have different standards and requirements as regards data documentation. More importantly, however, the main role of all three is to *support* research, not direct it: the highest standards of data documentation can only be determined by researchers themselves. This means that, rather than expect top-down regulation, domain specialists should organize themselves and take the bottom-up initiative to develop standards that conform to FAIR guidelines, and demonstrate the feasibility of technical solutions to data integration. Although professional associations such as the EAA have no mandate to promulgate such standards, they can play an important role in channelling and advertising the work of interest groups such as FIDO, an EAA 'community' with a remit to draft documentation standards for archaeological field surveying.⁵ Once such efforts gain momentum, they could become standard practice within the international research community, and could then be adopted by funding bodies, heritage management authorities, and data repositories. For legacy datasets, a large funding programme (such as that alluded to above) might simply impose FAIR-aligned standards for retrospective documentation.

4 CONCLUSIONS AND RECOMMENDATIONS

To summarize the above, Mediterranean field survey data are the prime candidate for digital integration, because they document the same thing (the surface archaeological record) in broadly the same way. We presented four possible routes to digital data integration in section 2 – narrative integration,

5 https://www.e-a-a.org/EAA/Navigation_Communities/FIDO.aspx.

metadata integration, question-specific integration, and data merging – and, in section 3, discussed the viability of these approaches in the current circumstances and in the long term. We then outlined a fifth approach – semantic modelling coupled with LOD – which seems to be the only sustainable route in the long term, as it can not only be used retrospectively, to integrate legacy datasets, but can also be implemented easily in future projects, and it holds potential not just for Mediterranean field survey data, but also for archaeological data in general. We have also defined two core challenges that we now face, which are not unique to field surveying but are common to most (if not all) other data-generating archaeological activities:

- The integration of irreplaceable ‘legacy’ data, requiring a huge effort on the part of data owners to bring the documentation and archiving up to FAIR standards, irrespective of the precise technical form of the integration;
- The diffusion and adoption of best practice in documenting and archiving future field studies according to FAIR standards, in a field that is fragmented along both national and professional lines.

Such challenges cannot be overcome in the short term. Our recommendations for the medium term (*i.e.*, the next 10 years) are therefore:

- State-sponsored data repositories should adopt semantic modelling and LOD as their new technical standard
- Funding agencies should enforce digital archiving at a state-sponsored repository
- Funding agencies should enable the ‘retrospective’ FAIRification of legacy survey datasets
- Academic reward systems should be further changed to promote data rescue (*i.e.*, archiving and publication) initiatives
- Professional archaeologists, working through organizations such as IFA, INRAP, and EAA, should discuss, draft, and adopt international documentation standards
- More appropriate documentation and archiving skills training should be integrated into our archaeology education programs in order to increase both awareness and the prevalence of technical capabilities

REFERENCES

- Alcock, S. 1993. *Graecia Capta*. Cambridge: Cambridge University Press.
- Alcock, S. 2000. “Extracting meaning from ploughsoil assemblages: assessments of the past, strategies for the future.” In *Extracting meaning from ploughsoil assemblages*, edited by R. Francovich and H. Patterson, 1-4. Oxford: Oxbow.
- Alcock, S, and J. Cherry. 2004. “Introduction.” In *Side by side survey. Comparative regional studies in the Mediterranean world*, edited by S. Alcock and J. Cherry: 1-9. Oxford: Oxbow. DOI:DOI:10.51952/9781447328353.ch001.
- Attema, P., J.L. Bintliff, M. van Leusen, P. Bes, T. de Haas, D. Donev, W. Jongman, E. Kaptijn, V. Mayoral, S. Menchelli, M. Pasquinucci, S. Rosen, J. García Sánchez, L. Gutierrez Soler, D. Stone, G. Tol, F. Vermeulen, and A. Vionis. 2020. “A guide to good practice in Mediterranean surface survey projects.” *Journal of Greek Archaeology* 5: 1-62. DOI:10.32028/9781789697926-2.
- Attema, P., G. J. Burgers, and M. Van Leusen. 2010. *Regional pathways to complexity*. Amsterdam: Amsterdam University Press. DOI:10.1017/9789048513444.
- Attema, P., P. Carafa, W. Jongman, C. Smith, R. Bronkhorst, M. Capanna, T. de Haas, M. van Leusen, G. Tol, R. Witcher, and N. Wouda. 2021. “The Roman Hinterland Project: Integrating Archaeological Field Surveys around Rome and Beyond.” *European Journal of Archaeology* 25 (2): 238-258. DOI:10.1017/eaa.2021.51.
- Bintliff, J.L. 1997. “Regional Survey, Demography, and the Rise of Complex Societies in the Ancient Aegean: Core-Periphery, Neo-Malthusian, and other Interpretive Models.” *Journal of Field Archaeology* 24: 1-38. DOI:10.1179/jfa.1997.24.1.1.
- Blanton, R. 2001. “Mediterranean myopia.” *Antiquity* 75: 627-29. DOI:10.1017/S0003598X00088918.
- Collins-Elliott, S. 2022. “Measuring rural economic development through categorical data analysis in southern Etruria and Latium (400 BC-50 AD).” In *The rural foundations of the Roman economy: New approaches to Rome’s ancient countryside from the Archaic to the Early Imperial period*, edited by P. Attema and G. Schörner, 19-33. Heidelberg. DOI:10.11588/propylaeum.930.c12272.
- Cooper, A. and C. Green. 2015. “Embracing the Complexities of ‘Big Data’ in Archaeology: the Case

- of the English Landscape and Identities Project.” *Journal of Archaeological Method and Theory* 23(1): 271-304. DOI:10.1007/s10816-015-9240-4.
- De Haas, T.C.A. and P.M. van Leusen. 2020. “FAIR survey: improving documentation and archiving practices in archaeological field survey through CIDOC CRM.” *Fasti Online Documents & Research* 12. <http://www.fastionline.org/docs/FOLDER-sur-2020-12.pdf>.
- De Ligt, L. 2012. *Peasants, Citizens and Soldiers. Studies in the demographic history of Roman Italy*. Cambridge: Cambridge University Press.
- Fentress, E. 2000. “What are we counting for?” In *Extracting Meaning from Ploughsoil Assemblages*, edited by R. Francovich and H. Patterson, 44-52. Oxford: Oxbow.
- Foss, P., and R. Schindler, eds. 2008. *MAGIS: Mediterranean Archaeological GIS*. Electronic document. <http://cgma.depauw.edu/MAGIS/> (accessed May 8, 2021).
- Gillings, M. 2001. “The utility of the GIS approach in the collection, management, storage and analysis of surface survey data.” In *The Future of Archaeological Field Survey in Europe*, edited by J. Bintliff, M. Kuna, and N. Venclova, 105-20. Sheffield: Equinox.
- Kintigh, K., J. Altschul, M. Beaudry, R. Drennan, A. Kinzig, T. Kohler, W. Limp, H.D.G. Maschner, W.K. Michener, T.R. Pauketat, P. Peregrine, J.A. Sabloff, T.J. Wilkinson, H.T. Wright, and M.A. Zeder. 2014. “Grand challenges for archaeology.” *American Antiquity* 79(1): 5-24. DOI:10.1073/pnas.1324000111.
- Launaro, A.. 2011. *Peasants and slaves. The rural population of Roman Italy (200 BC to AD 100)*. Cambridge: Cambridge University Press.
- McCoy, M.D. 2017. “Geospatial Big Data in Archaeology: Prospects and problems too great to ignore.” *Journal of Archaeological Science* 84, 74-94. DOI:10.1016/j.jas.2017.06.003.
- Palmisano, A., A. Bevan, and S. Shennan. 2018. “Regional Demographic Trends and Settlement Patterns in Central Italy: Archaeological Sites and Radiocarbon Dates.” *Journal of Open Archaeology Data* 6: 2. DOI:10.5334/joad.43.
- Samuels, T. 2019. “*Recovering Rural Non-Elites: Commoner Landscapes and Rural Infill in the Roman Middle Republic*.” PhD diss., University of Michigan.
- SIKB, n.d. “BRL SIKB 4000 Archeologie.” Accessed April 11, 2023. <https://www.sikb.nl/archeologie/richtlijnen/brl-sikb-4000>.
- Smith, M. and P. Peregrine. 2012. “Approaches to Comparative Analysis in Archaeology.” In *The Comparative Archaeology of Urban Societies*, edited by M. Smith, 4-18. Cambridge: Cambridge University Press. DOI:10.1017/CBO9781139022712.004.
- Stone, D. 2004. “Problems and Possibilities in Comparative Survey: A North African Perspective.” In *Side-by-Side Survey: Comparative Regional Studies in the Mediterranean World*, edited by Susan E. Alcock and John F. Cherry, 132-143. Oxford: Oxbow Books.
- Terrenato, N. 2004. “Sample Size Matters! The Paradox of Global Trends and Local Surveys.” In *Side by Side Survey. Comparative Regional Studies in the Mediterranean World*, edited by Susan E. Alcock and John F. Cherry, 36-48. Oxford: Oxbow Books.
- Van Leusen, P.M. 2001. “Archaeological Data Integration.” In *Handbook of Archaeological Sciences*, edited by A.M. Pollard and D.R. Brothwell, 575-583. London: John Wiley & Sons.
- Van Leusen, P.M. 2002. *Pattern to Process: Methodological Investigations into the Formation and Interpretation of Spatial Patterns in Archaeological Landscapes*. Unpublished PhD thesis, University of Groningen.
- Wilkinson, M., M. Dumontier, and I. Aalbersberg. 2016. “The FAIR Guiding Principles for Scientific Data Management and Stewardship.” *Scientific Data* 3: 160018. DOI:10.1038/sdata.2016.18.
- Witcher, R.E. 2006a. “Broken Pots and Meaningless Dots? Surveying the Rural Landscapes of Roman Italy.” *Papers of the British School at Rome* 74: 39-72. DOI: 10.1017/S0068246200003226.
- Witcher, R.E. 2006b. “Settlement and Society in Early Imperial Etruria.” *Journal of Roman Studies* 96: 88-123. DOI:10.3815/000000006784016161.

Isotopes, Isoscapes, and the Search for Geographic Origins: Unrealized Potential or Unrealistic Expectations?

Jason E. Laffoon and Till F. Sonnemann

1 INTRODUCTION

Isotope analysis has become an increasingly popular and utilized tool to investigate geographic origins in archaeology. Since the first application of isotope methods to assess human migrations and mobility over thirty years ago (Ericson 1985), these methods have developed to become one of the most commonly employed approaches to the study of human (and animal) paleomobility in archaeological research. Traditionally, most applications of this method have focused on simply distinguishing between locals and nonlocals. Over the last decade, however, there has been a concerted effort to develop spatially explicit databases of baseline (bioavailable) strontium and oxygen isotope variation. When applied at large scales these data can be used to generate maps or predictive models (isoscapes) of spatial isotopic variation in order to assess individual geographic origins (Bowen 2010; West *et al.* 2010). These isoscapes have been developed for different isotope systems, various sample materials, and many areas of the world at multiple scales from regional, to sub-continental, to global (*e.g.*, Adams *et al.* 2019; Bataille and Bowen 2012; Bataille *et al.* 2012; 2018; 2020; Britton *et al.* 2020; Funck *et al.* 2021; Hedman *et al.* 2018; Hobson *et al.* 2012; Laffoon *et al.* 2012; Lugli *et al.* 2021; Scaffidi and Knudson 2020). Nevertheless, to date, there has been insufficient research testing the reliability of these isoscapes for their intended purpose of determining individual origins. Despite some preliminary evidence of the efficacy of such isoscapes for archaeological and forensic human provenance research (Bataille *et al.* 2021; Colleter *et al.* 2021; Ehleringer *et al.* 2010; Font *et al.* 2015a; Laffoon *et al.* 2017), much more systematic testing of the validity of these models, using individuals of known origin, is needed before these can be more broadly and effectively applied to archaeological studies of migration and mobility, generally, and of individual origins in particular.

In this paper, we assess the reliability of extant Circum-Caribbean strontium and oxygen isoscapes using isotope data obtained from modern individuals of known childhood origins. The current study represents a follow up to a previous study that used dual isotopes and isoscapes (strontium and oxygen) to test and validate this approach. In this previous study (Laffoon *et al.* 2017), one modern individual of known origin from Caracas (Venezuela), and two (nonlocal) archaeological individuals recovered from sites on Trinidad and Cuba were tested. The results of this previous study demonstrated that: many areas within the broader macro-region (Circum-Caribbean) could be eliminated as possible places of origin based on a single isotope value; potential places of origin were further narrowed by using two isotopes proxies; the approach accurately identified

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Caracas as a possible place of origin for the modern individual; and the suspected geographic origins of the archaeological individuals (based on other lines of evidence) were consistent with the possible origins based on the dual-isoscape approach (Laffoon *et al.* 2017). The original study, however, only included one (modern) known origin individual, which is insufficient to robustly test the isoscape approach. The current study includes further testing of the isoscape method based on six additional modern, known-origin individuals including four individuals with just strontium isotope data, and two more with both strontium and oxygen isotope data. The results of the current study demonstrate considerable variation in the efficacy of the isoscape approach for constraining childhood origins and illustrate areas where the predictive models may need to be improved before they can be more widely utilized for the accurate and precise identification of individual geographic origins in archaeological and forensic research.

Placing this chapter within the broader aims of this volume, exploring promises and impediments of digital archaeology, isoscapes are increasingly popular tools for investigating origins in widely diverse research fields. These include sourcing and authentication studies in food science (Schellenberg *et al.* 2010), tracing the illicit trade in elephant ivory (Van der Merwe *et al.* 1990) and illegal drugs (Galimov *et al.* 2005), tracking animal migrations in wildlife ecology (Hobson *et al.* 2010), determining the origins of human remains from forensic contexts (unidentified individuals, mass graves) (Chesson *et al.* 2018), and exploring human migrations in archaeology (Lee-Thorp 2008). This increased popularity can be attributed to several factors: such as the empirical nature of isotope methods; the increased throughput, reduced costs and improved accuracy of isotope measurements; the ability to apply them to a broad range of materials and research questions; and perhaps most importantly their vast potential for answering one of the most fundamental of questions: ‘where does someone (or something) come from?’. To date, however, the vast potential of isoscape approaches for researching origins has yet to be realized in part due to the fact that the science is quite young and fast developing, because large-scale reliable isoscapes are not yet available for many regions of the world, and due to the fact that extant isoscapes have not yet been systematically tested to validate that they are actually effective tools for such purposes. This case study

represents an explicit attempt to test the validity of current Circum-Caribbean isoscapes for the purpose of constraining human geographic origins.

2 ISOTOPE PRINCIPLES

Isotope analysis has a long history of applications in archaeological research. Analysis of the radioactive isotopes of carbon (carbon-14) forms the basis of the most commonly employed absolute dating method in archaeology. Stable isotope analyses have also been widely used for dietary studies (carbon and nitrogen) and for climate (oxygen) and environmental (carbon and oxygen) reconstructions (Lee-Thorp 2008). Isotope analysis of human remains was first proposed and applied to the study of human mobility using strontium isotopes (Ericson 1985) and later oxygen isotopes (Fricke *et al.* 1995; Schwarcz *et al.* 1991). Over the last several decades strontium and oxygen isotopes have been increasingly applied in archaeological research, to the extent that they now form, in addition to aDNA, one of the most commonly utilized analytical methods in paleomobility studies (Makarewicz and Sealy 2015).

Strontium isotope analysis is based on the following principles (see review in Bentley 2006). Of the four naturally occurring isotopes of strontium, three are stable (^{84}Sr , ^{86}Sr , and ^{88}Sr), and one is radiogenic (^{87}Sr) produced by the decay of ^{87}Rb with a half-life of roughly 4.88×10^{10} years (Faure and Mensing 2005). The amount of ^{87}Sr in rocks and minerals is thus a function of the amount of ^{87}Rb (relative to strontium) in the parent material and time, and the ratio of interest is reported as $^{87}\text{Sr}/^{86}\text{Sr}$. Strontium isotopes display geographic variation based on the age and lithology of underlying bedrock (Faure and Mensing 2005). Due to chemical weathering and leaching, strontium derived from bedrock enters soil and groundwater, is taken up by plants and enters the food web (referred to as biosphere or bioavailable strontium). As strontium is chemically similar to calcium, the former readily replaces the latter in various minerals including hydroxyapatite, the main mineral component of bones and teeth (Bentley 2006). Therefore, in vertebrate animals, including humans, strontium tends to be concentrated in the skeletal system. Whereas bones remodel throughout life, the crowns of teeth are comprised of dental enamel which does not undergo remodelling and thus retains the biochemical and isotopic signatures of the period during which it formed. The enamel of human deciduous (baby) teeth forms and mineralizes *in utero* until infancy, while enamel of permanent teeth

forms at different periods per tooth type, ranging from early infancy (first molars) to adolescence (third molars), although most tooth crowns form primarily during childhood (Hillson 1996). Therefore, human teeth preserve a permanent isotopic record, or biogeochemical passport, of the location where they formed as these will not change even after subsequent migration to a new location.

The principles of oxygen isotope analysis of human teeth for paleomobility studies reflect both similarities and differences with the strontium isotope method. Whereas both methods are primarily applied to teeth and can be used to determine childhood origins and thus infer migration, the main difference lies in the sources of isotopic variation. Oxygen in biological or biogenic tissues (including human bones and teeth) is predominantly derived from consumed water (Daux *et al.* 2008; Longinelli 1984; Luz *et al.* 1984; Pederzani and Britton 2019; Podlesak *et al.* 2008). In most, but certainly not all, archaeological contexts, drinking water was obtained from local water sources, which are ultimately derived from precipitation (rain, snow). Oxygen isotopes ($\delta^{18}\text{O}$) in precipitation vary globally based on various geographic and climatic variables such as latitude, altitude, distance to coast, and temperature of precipitation (Dansgaard 1964; Gat 1996). Several decades of research have been devoted to understanding spatial and temporal variation in oxygen isotopes as these are one of the most reliable proxies for (paleo)-climate studies (Bowen and Wilkinson 2002). Because strontium and oxygen isotopes vary independently, they represent useful complementary isotope proxies, and when combined can potentially provide more interpretive power than either isotope proxy in isolation.

In paleomobility studies, strontium and/or oxygen isotope analysis is most commonly conducted on dental enamel. Many studies have primarily focused on using isotope data to distinguish between locals (locally born and raised individuals with a local isotope signal) and nonlocals (individuals with a nonlocal signal who were born and raised elsewhere and who subsequently migrated to the site/location where they were interred). One of the main interpretive limitations of this approach is that nonlocal individuals originating from isotopically similar regions are falsely identified as locals (false negatives). Another critical limitation is that isotope signals are never unique to a single location and many regions/locations are isotopically indistinguishable. This issue is known as equifinality (Price *et al.* 2007) and the implication

of this is that it is very difficult, if not impossible, to pinpoint a specific origin based on isotope data alone.

Additionally, there has been substantial discussion, and little consensus, concerning how local isotope ranges should be estimated (*e.g.*, Valentine *et al.* 2015; Wright 2005). For strontium isotopes, many early studies (Ericson 1985; Nelson *et al.* 1986; Sealy *et al.* 1991) tended to focus on strontium isotope analysis of both enamel and bone with the assumption that owing to remodelling, bone $^{87}\text{Sr}/^{86}\text{Sr}$ should eventually equilibrate to the local isotope signal. Subsequent research has demonstrated that buried bone is highly susceptible to diagenetic alteration of biogenic $^{87}\text{Sr}/^{86}\text{Sr}$ (Budd *et al.* 2000; Hoppe *et al.* 2003; Trickett *et al.* 2003), and that the degree of post-mortem contamination of archaeological bone $^{87}\text{Sr}/^{86}\text{Sr}$ is highly variable and difficult to assess or remove (Price 1989). As such, strontium isotope analysis of bone as a sampling material has fallen out of favour, with the exception of cremated bone, which appears to retain the *in vivo* isotope signal (Snoeck *et al.* 2018). In the absence of independent data to assess local strontium isotope ranges, statistical assessments of human isotope data have also been used to generate local range estimates (Wright 2005), but these generally rely on dubious assumptions including that the majority of the sample population is of local origin, and that isotopic variation within the local population is random. One of the most commonly used methods to assess local strontium isotope ranges is to measure $^{87}\text{Sr}/^{86}\text{Sr}$ in locally derived materials, such as soils, water, animals and plants. In general, non-motile archaeological faunal remains are considered the best proxies for local range estimates (Price *et al.* 2002), but there is substantial variation in the targeting of sampling materials and species (Evans *et al.* 2010; Grimstead *et al.* 2017).

3 ISOSCAPES

Until fairly recently, the vast majority of isotope studies of human paleomobility represent site-based case studies limited to identifying local and nonlocal individuals. While these have been highly successful in this regard and for explorations of human paleomobility patterns more generally, one valid critique (Pestle *et al.* 2013) is that they provide little or no insight into the geographic origins of nonlocals (migrants). Subsequent studies have also made significant progress in our understanding of spatial isotopic variation at larger spatial scales. Much of this research has focused on developing larger regional databases of bioavailable strontium isotope ratios (BASR), based on a wide range

of different sample proxies. These are essential for ‘pushing the envelope’ of isotope migration studies beyond the identification of nonlocals and towards a true provenance approach permitting scientific explorations of the geographic origins of people (or animals, materials, artefacts). It should be kept in mind that isotopic provenance studies are inherently exclusionary, meaning that the isotope data can only be used to exclude, and not pinpoint, possible places of origin. Nonetheless, a good understanding of spatial isotope variation can in many cases permit more nuanced interpretations of human isotope data and can sometimes be used to vastly reduce the possible areas of origin for nonlocal individuals, especially in combination with other lines of evidence.

Furthermore, advances in isotope method and theory in other fields of study have led to further development of these approaches in archaeology. Specifically, isotope studies of modern animal migrations in the field of wildlife ecology led to increased attention to mapping stable isotope variation at greater spatial scales (*e.g.*, Hobson and Wassenaar 2018; Hobson *et al.* 2010). Owing at least in part to the very substantial dedication of resources (time, labour, money) required to collect and analyse appropriate sampling materials over large areas, digital solutions to the problem of large-scale isotope mapping were investigated. This led to the development, approximately a decade ago, of the concept of isoscapes: spatially explicit predictive models of isotope variation (West *et al.* 2009). Regional and global isoscapes for various isotope systems have also been developed. For example, precipitation oxygen isoscapes are based on large datasets of oxygen isotope measurements of water collected at various locations across the globe as part of the Global Network of Isotope in Precipitation (GNIP) project of the IAEA (IAEA/WMO 2016). Using various spatial statistics to interpolate between measured data forms the basis for predictive models (maps) of isotopic variation across the landscape (isoscapes). In this sense, the development and use of large-scale isoscapes for light stable isotopes (*e.g.*, oxygen, hydrogen, carbon, and nitrogen) is further advanced than those for strontium or lead (Pb). In fact, for several years, online platforms such as the Online Isotopes in Precipitation Calculator, and ISOMAP (Isoscape Modelling Analysis and Prediction) have provided invaluable tools for using isotope data for a wide range of research applications across various fields ranging from climate change to ecology to forensics.

However, compared to isoscapes for light stable isotopes, strontium isoscapes have been less widely used despite their enormous potential for provenance and mobility studies in archaeology and beyond. Fortunately, in the last several years strontium isoscapes have also been developed for many regions of the world, and recently even a global bioavailable strontium isoscape was published (Bataille *et al.* 2020). One of the main limitations to the broader application of strontium isoscapes is the fact that most examples have simply been published as figures within articles lacking associated code and as such, they are generally not very user friendly. This trend is expected to change dramatically in the coming years with the increased focus on digital archaeology (quantitative and computational approaches in archaeological research), the publication of associated programming codes for user-friendly applications (*e.g.*, Bataille *et al.* 2018), the increasing availability of large digital repositories of isotope data (IsoArch, <https://isoarch.eu/>), and the development of online tools for inputting and interpreting archaeological strontium isotope data such as the British Isotope Domains website of the British Geological Survey. One persistent limitation concerning the use of isoscapes in general, and strontium isoscapes in particular, in paleomobility and provenance research, is that there has been a general lack of validation and testing of their accuracy and efficacy.

3.1 Circum-Caribbean isoscapes

One of the main aims of the current study is to further assess the reliability of isoscapes for the determination of individual geographic origins based on enamel strontium and oxygen isotope data. In this regard, this study represents a continuation of a previous validation study with similar aims using Circum-Caribbean strontium and oxygen isoscapes (figure 1). The original Circum-Caribbean strontium isoscape represents a three-source mixing model (which incorporates strontium inputs from bedrock, sea spray, and atmospheric dust) originally developed by Bataille *et al.* (2012) and was tested on several hundred baseline strontium isotope measurements from Mesoamerica (Hodell *et al.* 2004) and the insular Caribbean (Laffoon 2012; Laffoon *et al.* 2012). The multi-source Circum-Caribbean strontium isoscape performs better than a traditional single source model (bedrock only) in predicting the observed baseline $^{87}\text{Sr}/^{86}\text{Sr}$ ratios in both regional datasets: Mean Absolute Error (MAE) = 0.00040, Root Mean Square

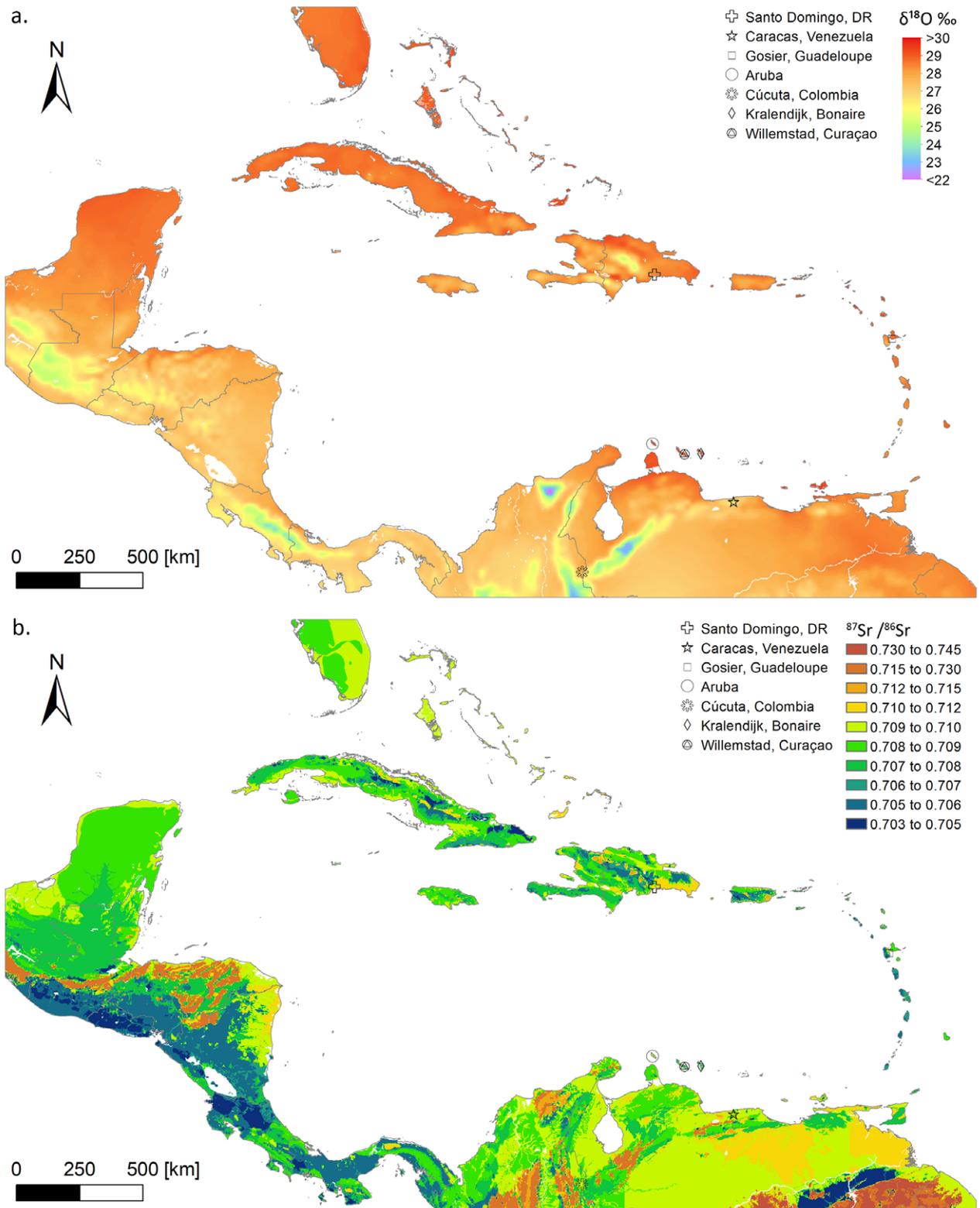


Figure 1: (a.) Enamel oxygen ($\delta^{18}\text{O}$) and (b.) bioavailable strontium ($^{87}\text{Sr}/^{86}\text{Sr}$) isoscapes of the Circum-Caribbean.

Error (RMSE) = 0.00087; and MAE = 0.00014, RMSE = 0.0010, respectively. Furthermore, the multi-source model is in good agreement with the range of (local) human $^{87}\text{Sr}/^{86}\text{Sr}$ ratios for dozens of sites from multiple islands and locations within the broader Caribbean (Laffoon 2012) as well as subsequent baseline measurements from previously unsampled or under-sampled regions. The enamel $^{87}\text{Sr}/^{86}\text{Sr}$ isoscape used in this paper is modified from the bioavailable multi-source mixing model of Bataille *et al.* (2012).

Within the insular Caribbean there is a spatial bias of representation in the original baseline bioavailable $^{87}\text{Sr}/^{86}\text{Sr}$ dataset (Laffoon *et al.* 2012) with much of the eastern and southern Caribbean well covered, while much of the northern (Bahamian archipelago) and western Caribbean (Haiti/Dominican Republic, Jamaica, Cuba) is represented by few data points relative to their land mass. A similar problem of spatial representation also plagues the bioavailable data from the mainland regions of the Circum-Caribbean with Mesoamerica very well represented, whereas much of Central America and Northern South America are represented by very few sampling locations or data points. Fortunately, further research has made substantial progress filling in some of the gaps in bioavailable $^{87}\text{Sr}/^{86}\text{Sr}$ data for many areas within the Circum-Caribbean: Puerto Rico (Pestle *et al.* 2013), Nevis and Carriacou (Giovas *et al.* 2016), Trinidad and Tobago (Ostapkowicz *et al.* 2017), Venezuela (Laffoon *et al.* 2018), the Bahamas and Turks and Caicos (Schulting *et al.* 2018), Barbados (Giovas *et al.* 2019), the Dominican Republic (Laffoon *et al.* 2019), Jamaica (Mickleburgh *et al.* 2019), Panama (Sharpe *et al.* 2021) and Cuba (Laffoon and Chinique de Armas 2022). Additionally, strontium isotope mapping on the Bahamian archipelago has demonstrated little or no influence of Sr inputs from atmospheric dust on bioavailable $^{87}\text{Sr}/^{86}\text{Sr}$ (Schulting *et al.* 2018). This insight suggests that a simpler two-source mixing model (including bedrock and sea spray) may adequately reflect the main sources of strontium to terrestrial Antillean ecosystems, although further research is required to assess if this is more broadly applicable across the entire Circum-Caribbean.

The Circum-Caribbean oxygen isoscape used herein is ultimately based on measurements of oxygen isotopes in precipitation from the GNIP (IAEA/WMO 2013) and the regionalized cluster-based water isotope prediction (RCWIP) model of Terzer *et al.* (2013). Details of the data conversion, reduction, and manipulation steps used to produce the oxygen

isoscape are reported in Laffoon *et al.* (2017). The precipitation oxygen isoscape was converted to an enamel isoscape by converting the water $\delta^{18}\text{O}$ values to enamel $\delta^{18}\text{O}$ values based on the equation of Chenery *et al.* (2012). This enamel oxygen isoscape is generally consistent with measured human and animal enamel $\delta^{18}\text{O}$ values from a wide range of sites and islands throughout the Antilles (Laffoon *et al.* 2013). Isotope analyses of bioarchaeological samples in the insular Caribbean combined with strontium and/or oxygen isoscapes have already contributed to investigations of human paleomobility patterns, animal migrations and the provenance of artefacts made from faunal skeletal remains (Laffoon *et al.* 2014; 2017; 2018).

4 MATERIALS AND METHODS

The validation tests were applied to multiple modern individuals of known (childhood) origins from various locations within the Circum-Caribbean: Santo Domingo, Dominican Republic; Caracas, Venezuela; Gosier, Guadeloupe; unspecified location in Aruba; Cúcuta, Columbia; Kralendijk, Bonaire; Willemstad, Curaçao. In total, isotope data from seven individuals from seven different locations were assessed (table 1). Five of these derive from previous studies by Plomp *et al.* (2019; 2020), four of which include only strontium isotope data, and one with both strontium and oxygen Sr; one individual was previously reported (Laffoon *et al.* 2017) and is re-assessed here; and one individual is from a new analysis for the current study. Dental samples were donated (anonymously) from living individuals who self-reported their geographic location (as well as diet, habits) at the time of tooth formation and mineralization via a questionnaire, and permission for analyses was approved by the Medical Ethics Review Committee of the VU University Medical Center (Plomp *et al.* 2019). The sampled dental elements represent two deciduous first molars (dm1) and five permanent third molars (M3). Deciduous first molars primarily mineralize *in utero* (AlQahtani *et al.* 2010) and thus their enamel $\delta^{18}\text{O}$ should not be influenced by the breastfeeding effect, which can elevate $\delta^{18}\text{O}$ values (Lin *et al.* 2003). We furthermore sampled the enamel near the cusps, which tends to form earlier than enamel near the tooth cervix in order to avoid material formed after birth. Third molar enamel crowns form from late childhood through adolescence (circa 8-14 years) and thus are not impacted by breastfeeding effects (AlQahtani *et al.* 2010).

Sample processing and analyses were similar for all individuals and are reported in detail elsewhere

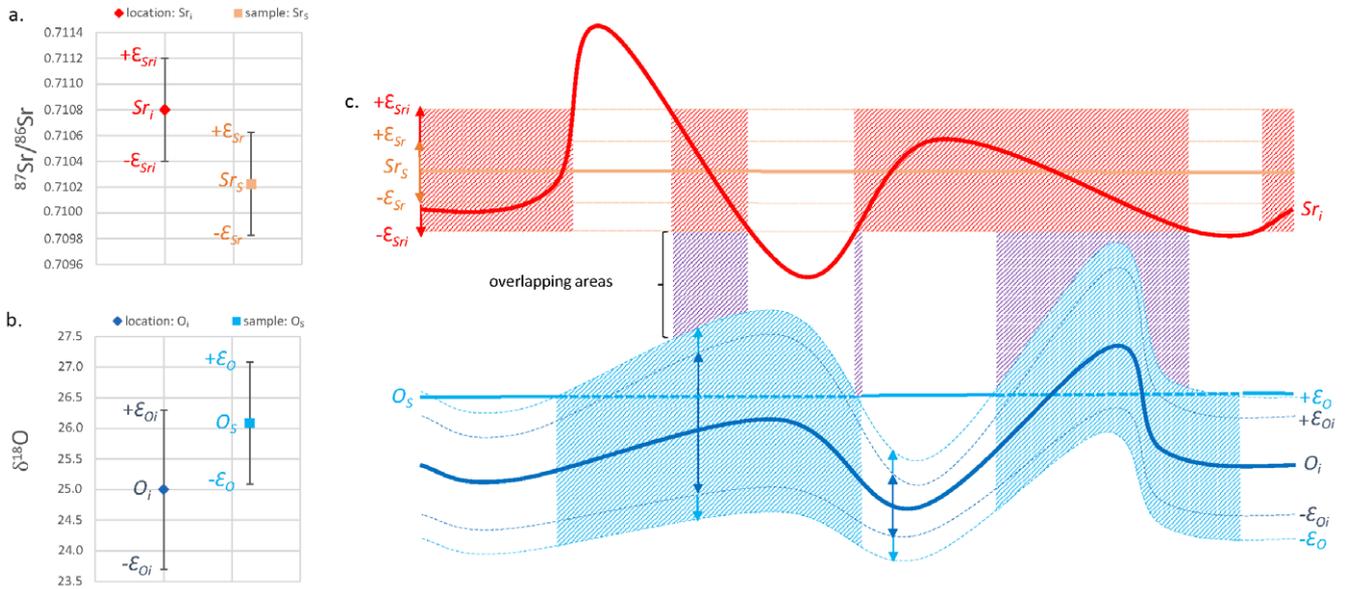


Figure 2: Sources of (a.) strontium and (b) oxygen uncertainties from measurements and raster map creation. Final areas from (c.) overlapping isotope uncertainty ranges.

(Laffoon 2012; Plomp *et al.* 2020). Briefly, dental samples were mechanically cleaned and then enamel was extracted using a hand-held dental drill. The samples were subsequently split in two for strontium and oxygen isotope analyses. For strontium isotope measurements, samples were dissolved in nitric acid, and then strontium was separated from the sample matrix using column chromatography with Sr-specific resin. Strontium isotope ratios were measured on a Thermo-Scientific TritonPlus Multi-Collector TIMS. Total procedural blanks were negligible, and instrument performance was monitored via the analyses of the international strontium standard (NBS-987) with a long-term mean $^{87}\text{Sr}/^{86}\text{Sr}$ of 0.710249 ± 0.0001 (1σ). Oxygen isotopes were measured on a Thermo-Finnigan DeltaPlus IRMS coupled to a Gasbench II interface. Oxygen isotope results are normalized using an internal laboratory standard (VICS), with a long-term reproducibility of the international reference material (NBS-19) for $\delta^{18}\text{O}$ of $<0.2\text{‰}$. Enamel oxygen isotope results are reported in the δ notation, in parts per thousand (‰) relative to the international VPDB standard and converted to VSMOW using the equation of Coplen (1988).

In terms of assessing geographic origins, we use the Interval Approach previously outlined in Laffoon *et al.* (2017). The Interval Approach is a simple way of assigning a yes (possible origin) or no

(not possible origin) to each raster cell (location) on a map (isoscape) by directly comparing the range of possible isotope values for each raster cell on the map with the measured isotope value(s), and associated individual error ranges/uncertainties, of the sample for strontium, oxygen, or both.

Both isotope databases had previously been uploaded into a GIS environment, where the globally estimated RCWIP oxygen data point values of approximately $18 \text{ km} \times 18 \text{ km}$ distance were adjusted to match the strontium raster data set resolution of one km^2 using cubic spline interpolation. Both images were subsequently framed by a Caribbean boundary map (open source by <http://naturalearthdata.org>), creating two exactly overlapping maps (Laffoon *et al.* 2017), displaying only land coverage. These datasets form the base to calculate the interval approach results. The uncertainty ranges of each isotope value, as minimum and maximum extent, are compared with the isotope values by a logical operator. If the map values lie within the defined range, the logical operator assigns this pixel value one; if the value is outside the range, the pixel value is zero. The extent of this min-max range based on the combined uncertainties fills the interval of matching values, which defines the size of the remaining areas.

Regarding strontium, the combined errors of map variation (ϵ_{Sr_i}) and measurement uncertainty (ϵ_{Sr_s}) result

| Sample ID | Location | Country | element | source | $^{87}\text{Sr}/^{86}\text{Sr}$ | $^{87}\text{Sr}/^{86}\text{Sr}$ | $\delta^{18}\text{Oc}$ | $\delta^{18}\text{Oc}$ | $\delta^{18}\text{Oc}$ |
|-----------|---------------|------------|---------|--------|---------------------------------|---------------------------------|------------------------|-----------------------------|------------------------|
| | | | | | | | ‰ VPDB | ‰ VPDB | ‰ VSMOW |
| | | | | | <i>measured</i> | <i>2SE</i> | <i>measured</i> | <i>1σ</i> | <i>Coplen 1988</i> |
| V464_V1 | Caracas | Venezuela | dm | 1 | 0.71013 | 0.00001 | -4.9 | 0.1 | 25.8 |
| DR_WL | Santo Domingo | Dom. Rep. | M3 | 2 | 0.70831 | 0.00001 | -4.3 | 0.1 | 26.5 |
| V463_G2 | Le Gosier | Guadeloupe | dm | 3 | 0.70820 | 0.00001 | -4.5 | 0.1 | 26.2 |
| W4-B16 | Cúcuta | Columbia | M3 | 2 | 0.71175 | 0.00001 | | | |
| W6-B13 | ? | A/B/C | M3 | 2 | 0.70950 | 0.00001 | | | |
| W2-R8 | Willemstad | Curaçao | M3 | 2 | 0.70945 | 0.00001 | | | |
| W3-B4 | Kralendijk | Bonaire | M3 | 2 | 0.70926 | 0.00001 | | | |

Table 1: Isotope values and relevant sampling information of known origin individuals from the Circum-Caribbean area. Data sources: 1) Laffoon *et al.* 2017; 2) Plomp *et al.* 2019; 3) this study.

in a total error of ± 0.0008 , which defines the range added or subtracted as a general mean error. Regarding oxygen, a novel path was chosen: firstly, the population variance is calculated by taking the square of the standard deviation of all measured values, with mean value at 0.687132‰, which was then rounded up to the significant digit ~ 0.7 ‰. To this value, a measurement uncertainty of 0.1 (reflecting the typical uncertainty of oxygen isotope measurements) was added, resulting in 0.8‰ measurement uncertainty (ϵ_o). An additional source of error was defined by the individual uncertainty for each data point from the RCWIP database (ϵ_{oi}) which was transferred and interpolated to each individual pixel accordingly, ranging within the map between 0.9 and 1.4‰. To this floating error range, the measurement uncertainty of ± 0.8 ‰ was added respectively. Based on the rules of propagating error, the square root of the sum of the squares of each source of uncertainty formed the total error for each pixel. This approach produces a greater uncertainty range for the oxygen results than previously calculated (Laffoon *et al.* 2017), producing a larger potential region of origin, but reducing the possibility of false positive results.

For samples where both strontium and oxygen values exist, these resulting maps once again were compared by a logical operator, leaving out all areas where either oxygen or strontium had turned out zero (figure 2). Figure 2 is a graphical representation of how the interval approach defines overlapping areas by cancelling out the rest, using a range of hypothetical values, and associated errors, for both strontium and oxygen (y-axes) and hypothetical variation of both over geographic location (x-axis).

5 RESULTS

The strontium and oxygen isotope measurements and relevant sample information are listed in table 1. The results of the Interval Approach are presented in figure 3 (using both strontium and oxygen isoscapes) and figure 4 (using only strontium isoscapes). We assess the effectiveness of the Interval Approach in terms of both accuracy and precision. In this context, accuracy refers to whether or not the Interval Approach correctly identifies the known geographic origin of the individual as a potential place of origin, whereas precision refers to the extent that the Interval Approach constrains the number of potential places of origin within the overall map. In this section we present the results on a case-by-case basis starting with the three samples for which both strontium and oxygen isotopes were measured.

Individual V1 was previously analysed and discussed in the original proof of concept study (Laffoon *et al.* 2017). We reanalysed it herein using a slightly modified version of the Interval Approach, namely with an expanded range of uncertainty for the oxygen isotope measurements (see paragraph 6.4). Ultimately, the results of this re-analysis with Interval Approach are very consistent with those of the original study. More specifically, separately both the strontium and oxygen isoscapes greatly constrain the potential places of origin for this individual but when the two isoscapes are combined using the Interval Approach the potential places of origin are even more constrained (figure 3). In this case the method is both accurate in the sense that Caracas (the known origin for this individual) is correctly identified as a potential

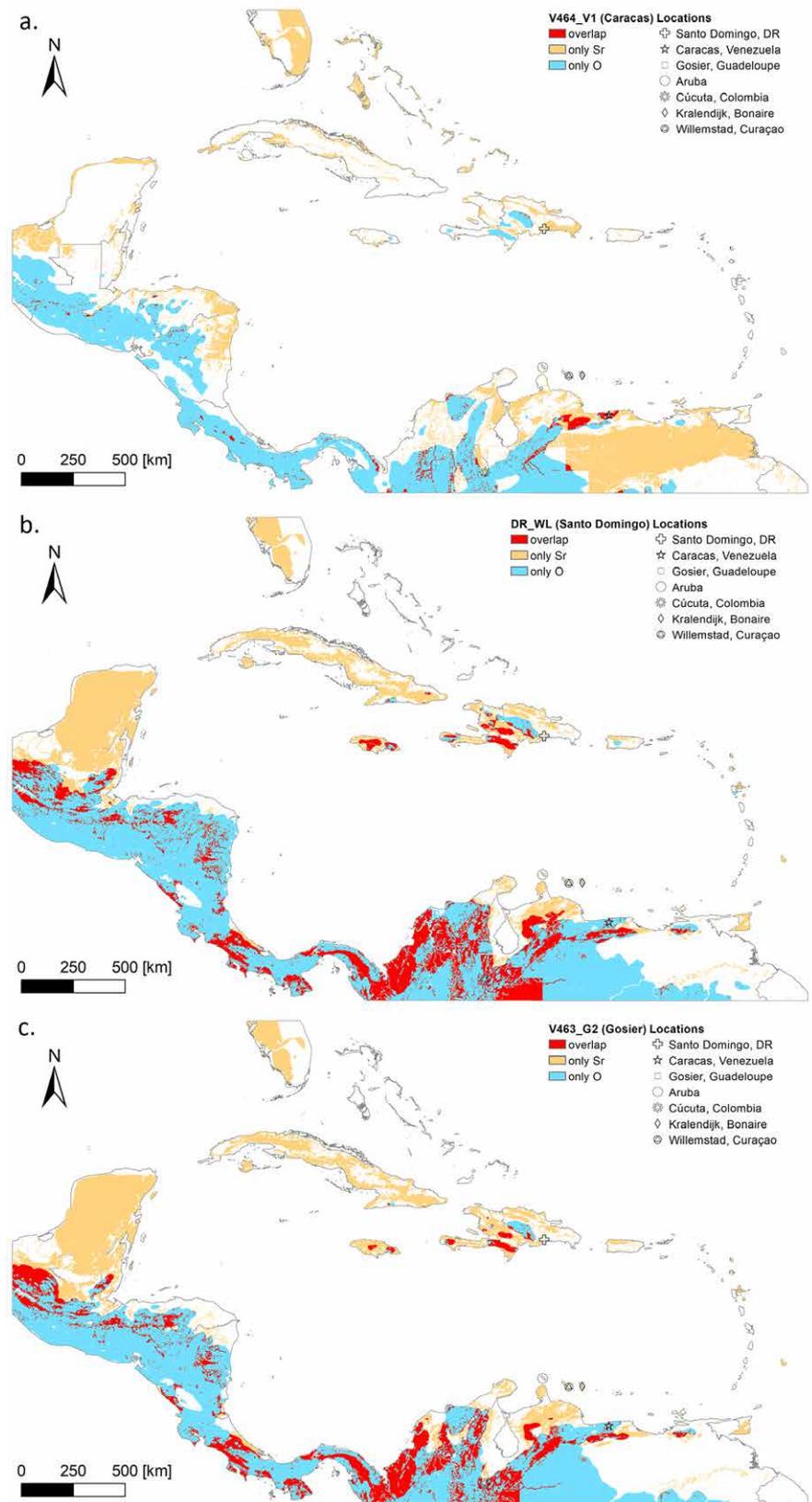


Figure 3: Results of the Interval Approach applied to strontium and oxygen isotope data and corresponding isoscapes.

place of origin, and precise in that the vast majority of the map area (>90% of the total raster cells) is excluded as a place of origin.

For Individual WL, the model results were both less accurate and less precise than for Individual V1. Santo Domingo, the known location of origin, was not identified as a potential place of origin. However, a few small areas, several kilometres to the west of the city were corresponding positively (figure 3). Similar to the case for Individual V1, the combination of the strontium and oxygen isoscapes reduced the number of potential places of origin substantially compared to the results of either one individually. In terms of precision, the number of potential places of origin was greatly constrained but less so than the case for Individual V1. More specifically, on the mainland, the model identified many scattered potential places of origin throughout Central America, and north-western South America. Within the insular Caribbean, most islands were excluded but potential places of origin were identified in much of Jamaica, large portions of southwestern Hispaniola (Haiti and the Dominican Republic), and few tiny pockets in south-eastern Cuba.

As expected, the overall model results for Individual G2 are similar to those of Individual WL since they possess very similar isotope values for both strontium and oxygen (figure 3). However, the model results for Individual G2 are far less accurate than for Individual WL. Interestingly, the eastern half of Guadeloupe (Grande-Terre) is identified as a potential place of origin based on strontium but not on oxygen isotopes. When combined, in the Interval Approach, not only is the known origin (in Le Gosier, Grande-Terre, Guadeloupe) excluded as a potential place of origin but so is the whole island of Guadeloupe, as well as the entire eastern Caribbean (Lesser Antilles archipelago). In this case, the strontium isoscape is much more accurate than the oxygen isoscape. For Individual G2 the precision is similar to Individual WL when both isoscapes are combined with large but dispersed potential places of origin throughout Central America, large portions of north-western and northern Southern America, and relatively few and small areas of Jamaica, south-western Hispaniola, and a tiny area of south-eastern Cuba identified.

For the remaining four individuals only strontium isotope data are available. For individual B16 with known origins in Cúcuta, Columbia, the model results did not accurately identify this location as a potential place of origin. However, numerous other locations in Columbia, including several relatively constrained

pockets in the highlands, including areas in the east somewhat near Cúcuta were identified as potential places of origin (figure 4). The model results for this individual were the most precise in the sense that the greatest area within the map was excluded as a potential place of origin relative to the other samples in this study. Interestingly, the model results primarily only identify relatively small and isolated locations in inland and highland areas of the Circum-Caribbean as possible places of origin for this individual. This pattern probably reflects the fact that individual B16 has a fairly high $^{87}\text{Sr}/^{86}\text{Sr}$ ratio (0.71175) that is more characteristic of older, continental geological settings primarily underlain by metamorphic bedrock. In addition to possible locations in Columbia, the model results also identify potential origins in very restricted areas of Venezuela, Panama, Nicaragua, Honduras, Cuba and Hispaniola. The latter two seem unlikely on the basis of empirical baseline $^{87}\text{Sr}/^{86}\text{Sr}$ data for the insular Caribbean where such high ratios have only been reported for Trinidad and Tobago (Laffoon *et al.* 2012; Ostapkowicz *et al.* 2017).

The remaining three samples for which only strontium isotope data are available have known origins in the so-called ABC islands (Aruba, Bonaire, Curaçao) located in the southern Caribbean just north of the coast of central Venezuela. For individual B13 it is only known that the origin is from one of the three ABC islands, whereas individual R8 has known origins from Willemstad, Curaçao and individual B4 originates from Kralendijk, Bonaire. All three individuals have very similar $^{87}\text{Sr}/^{86}\text{Sr}$ ratios and hence the model outputs for all three are highly comparable (figure 4). For these three individuals the model outputs are neither particularly accurate nor precise. All three model outputs correctly identify at least two of the ABC islands as a potential place of origin. For R8 and B4 all islands are identified as potential locations, while for B13 only Aruba and Curaçao are within the range. Some neighbouring areas of northern coastal Venezuela are also identified as such. The model outputs are less precise than the other samples in this study with a fairly reduced area of the map excluded as potential places of origin, and by consequence, a fairly large area of the map identified as possible places of origin for all three individuals.

6 DISCUSSION AND CONCLUSIONS

The relatively high degree of spatial variation in baseline isotope values in the Circum-Caribbean (figure 1), particularly for strontium, offers substantial

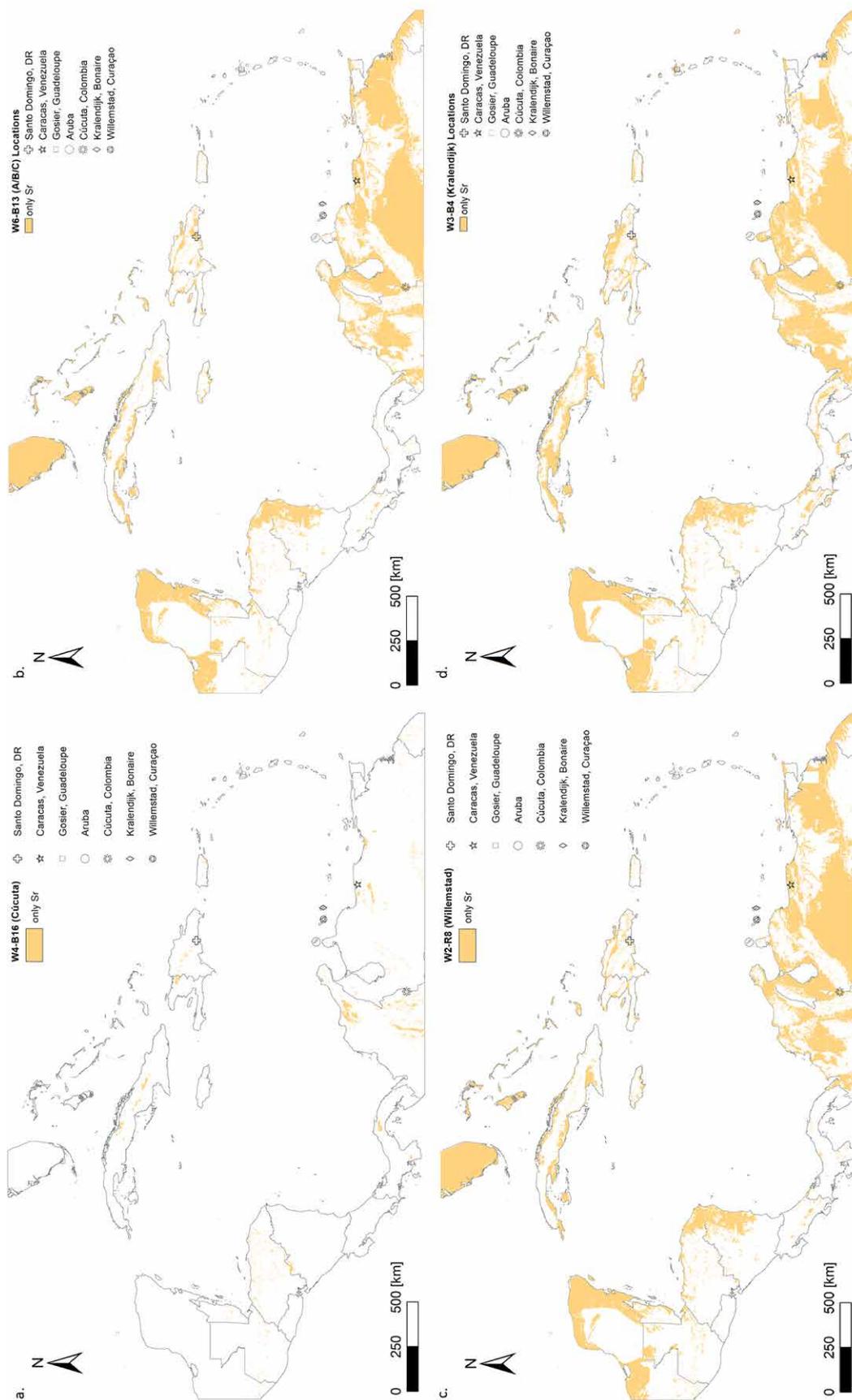


Figure 4: Results of the Interval Approach applied to strontium isotope data and corresponding isoscape.

potential for the application of isotopes and isoscapes to investigations of the geographic origins of a wide range of biogenic materials, including examinations of the childhood origins of individual humans from archaeological and forensic contexts. The application of the Interval Approach outlined herein to modern individuals with known geographic origins permits further assessment of the validity of this method. The model results of the Interval Approach for seven individuals detailed above raise numerous discussion points.

A previous study (Laffoon *et al.* 2017) using the same isoscapes and similar methods (*i.e.*, dual isoscapes and the Interval Approach) was applied to an individual from Caracas, Venezuela (V1, figure 3a). The results of this previous study (Laffoon *et al.* 2017) indicated a high degree of accuracy and precision when both strontium and oxygen isotopes were combined. This analysis was replicated herein with a slightly modified method but with identical results. More specifically, the origin identified by the model could be pinpointed to the area around Caracas and the nearby Venezuelan coastal range and thus was highly consistent with the known origin for this individual in Caracas. This example represents the best-case scenario for the overall method and approach. Unfortunately, the results for the other six individuals in this study were much more variable and less promising.

For the other two individuals for whom both strontium and oxygen isotope data were available (WL from Santo Domingo, Dominican Republic; and G2 from Gosier, Guadeloupe) the model results were somewhat less precise than for individual V1 but large areas of the Circum-Caribbean map (>50%) were excluded as potential places of origin. Since the isotope method for assessing origins is essentially exclusionary, the approach could be considered partially successful in the sense that many possible areas of origin have been excluded. However, much more concerning is the fact that the model outputs for both individuals were inaccurate (*i.e.*, did not correctly identify the known origin as a potential place of origin). One difference between these two cases is that for individual WL, possible places of origin were identified fairly close (within ~10 km) to the actual location of origin in Santo Domingo. Whereas, for individual G2 the strontium isotope correctly identified the eastern half of Guadeloupe as a potential place of origin but this was excluded on the basis of the oxygen isotope. We consider these two examples as being partially

successful in the sense that while both are moderately precise, the former is only slightly inaccurate while the latter is accurate based on one isotope system but not the other.

Highly variable results were also obtained from the four samples for which only strontium isotope data was available. For Individual B16 (from Cúcuta, Columbia), the results were very precise (approaching the precision obtained for Individual V1) with >90% of the map area excluded as a potential origin. The result was not very accurate given that the known origin was not identified as a potential place of origin, however, similar to the case for Individual WL where other, not too distant (<50 km) areas of eastern Columbia were identified as such. The results for the last three individuals were the least promising in terms of both accuracy and precision: while the model results correctly identified areas within the known islands of origin, extremely large areas of the overall map remained as possible places of origin.

In general, the model results obtained from the Interval Approach were highly variable and, in most cases, not particularly promising. We highlight several issues that need to be addressed to further develop these methods and hopefully improve the accuracy and precision of the results. First, one possible concern may be the errors associated with the isotope measurements themselves. This, however, seems unlikely to be a major concern given that the measurement uncertainties are much smaller (in some cases by an order of magnitude) than: the normal variation in isotopes within a single (local) individual (Plomp *et al.* 2020), the variance within most (archaeological) populations measured to date, and the uncertainties associated with the isotope models themselves (Laffoon *et al.* 2017).

A second potentially confounding factor is the selection of the appropriate samples for isotope analysis. In this study, five teeth are third molars, which form during adolescence and thus are not impacted by breastfeeding effects. Two others are represented by deciduous first molars, which primarily form *in utero*. However, mineralization of deciduous first molars continues after birth, and it is possible that some of the sampled enamel from these teeth may reflect the breastfeeding period or a combination of enamel formed before and after birth, and therefore contain a mix of fetal and breastfeeding inputs. Other issues pertaining to the use of oxygen isotopes for provenance studies more generally include seasonal variation in oxygen isotope values and long-term climatic change (Pederzani and Britton 2019), the latter

of course being more relevant for archaeological than for modern cases. There are also numerous processes that may cause significant differences between measured $\delta^{18}\text{O}$ values of local precipitation (upon which the oxygen isoscapes are based) and the $\delta^{18}\text{O}$ of consumed water (which is the primary source of $\delta^{18}\text{O}$ in biogenic tissues) such as fractionation from water storage, the consumption of imported (bottled) water, and cooking practices such as boiling and brewing (Brettell *et al.* 2012; Lee-Thorp 2008; Pederzani and Britton 2019), in addition to the previously discussed uncertainties associated with the conversions between water and enamel isotope values.

In terms of the reliability of the isoscapes, as previously mentioned for the Circum-Caribbean there is a distinct spatial bias in the representativeness of sampling for baseline strontium isotope ratios, with much of the northern and western insular Caribbean, and vast areas of Central America and northern South America grossly underrepresented relative to their size. A recent study that developed and tested the first global-scale strontium isoscape found that predictive models underperformed in areas that lacked spatially representative bioavailable $^{87}\text{Sr}/^{86}\text{Sr}$ data (Bataille *et al.* 2020). A related issue concerns the geospatial models that are used to predict bioavailable $^{87}\text{Sr}/^{86}\text{Sr}$ at large spatial scales. In the Caribbean, recent studies have demonstrated a notable lack of input from atmospheric sources (*e.g.*, Saharan dust) on bioavailable $^{87}\text{Sr}/^{86}\text{Sr}$ for certain islands and archipelagos (Schulting *et al.* 2018) that contrast with the process-based models used to generate the Circum-Caribbean strontium isoscape used in this study (Bataille *et al.* 2012). Furthermore, newer more robust geospatial models utilizing machine-learning approaches (Bataille *et al.* 2018) have been recently developed and offer potential for improving existing isoscapes at multiple scales, including for the Circum-Caribbean. Although not relevant for the current validation test, it should also be noted that the spatial limits of the Circum-Caribbean isoscape place *a priori* constraints on the Interval Approach. In other words, the approach will only identify possible places of origin within the geographical boundaries of the isoscape model.

Perhaps the most problematic issue limiting the utility of the isotope/isoscape method for provenance studies of modern individuals is the globalization of the food industry. For example, the three individuals in the present study from the ABC islands all have $^{87}\text{Sr}/^{86}\text{Sr}$ ratios that exceed the measured range of bioavailable $^{87}\text{Sr}/^{86}\text{Sr}$ for these islands

(maximum = 0.70915), a value that is very close to the mean $^{87}\text{Sr}/^{86}\text{Sr}$ ratio of seawater (0.70918). It is possible that the limited sampling ($n=20$ samples in total) of biosphere $^{87}\text{Sr}/^{86}\text{Sr}$ has not been sufficient to reflect the overall variance of $^{87}\text{Sr}/^{86}\text{Sr}$ for these three islands. This seems like an unlikely explanation in this case, however, as most island and coastal settings can be characterized as having bioavailable $^{87}\text{Sr}/^{86}\text{Sr}$ reflecting a two end-member mixing model between bedrock and marine-derived strontium. In the case of the ABC islands, the bedrock values represent the low endmember of this mixing solution and marine strontium (from sea spray and/or precipitation) represents the high endmember. As such, terrestrial bioavailable $^{87}\text{Sr}/^{86}\text{Sr}$ is not expected to exceed that of seawater (~ 0.7092) for these islands, or most other islands of the Caribbean for that matter. In this context, it is more parsimonious that the high $^{87}\text{Sr}/^{86}\text{Sr}$ ratios of the three measured individuals from the ABC islands reflect the consumption of imported foods.

It is difficult to assess the impact of imported foods on $^{87}\text{Sr}/^{86}\text{Sr}$ ratios in human dental enamel and the effects may be highly variable both spatially and temporally. Previous studies using isotope analyses of strontium and oxygen of World War 2 casualties successfully identified the geographic origins of at least one individual, which was later confirmed by other lines of evidence (Font *et al.* 2015a). Another recent study was successful at precisely and accurately constraining the origin of historically documented individuals from early modern Brittany (Bataille *et al.* 2021; Colleter *et al.* 2021). There are also numerous forensic studies that have utilized various isotope measurements and geographic assignment models to investigate individual (modern) human origins with varying degrees of success (Bartelink *et al.* 2020; Chesson and Berg 2021; Chesson *et al.* 2018; Font *et al.* 2015b; Kamenov and Curtis 2017; Kramer *et al.* 2020; Lehn *et al.* 2015; Mehl *et al.* 2019; Meier-Augenstein and Fraser 2008). Other studies have attempted to assess the reliability of isoscapes, or baseline isotope datasets, against isotope data obtained from modern individuals but the results have been quite variable with some areas demonstrating congruencies and other areas major differences depending on location and the type of material sampled for isotope analyses (*e.g.*, Ammer *et al.* 2020; Kootker *et al.* 2020; Ueda and Bell 2021). These studies seem to suggest that the complications introduced by the globalized nature of the food economy are perhaps not insurmountable but may generally increase over time and with variable

impacts depending on the extent that people consume imported foodstuffs. The degree that people consume nonlocal foods (with isotope ratios that do not reflect local sources) may be further exacerbated in small countries or islands where a large proportion of food is imported, as is the case in much of the insular Caribbean nowadays. By contrast, in regions where most if not all consumed food and water is of local origin the globalized food industry may have little effect on biogenic isotope values or the reliability of the isotopic approach to provenance studies.

In summary, the results of this study are highly variable in terms of both precision and accuracy. In this regard, they demonstrate a more complicated and nuanced situation than the results of the original validation study (Laffoon *et al.* 2017) of the Circum-Caribbean isoscapes which was based on a single sample and was, perhaps purely by coincidence, the most accurate and precise of the seven samples included in the present expanded study. The general lack of precision for many of the cases presented herein is probably best considered an inherent limitation of the method and not particularly problematic from an interpretive perspective. In many regions of the world, including the Circum-Caribbean, large and/or numerous areas have similar or even identical strontium and/or oxygen isotope values and some values or ranges of values are often much more common than others. If the measured isotope values in any given sample happen to be common in the study area, the isoscape provenance method will be limited in its capacity to constrain the potential places of origin. On the other hand, if a given sample happens to possess an isotope value, for one or more isotope systems, that is less common or particularly rare in a given study area, the degree that the origins can be constrained (the precision of the method) can be greatly improved. The lack of accuracy is a much more serious and confounding problem in this context. Perhaps counter-intuitively, the isotopic provenance method may actually work better for archaeological cases than for modern ones owing to the aforementioned complications of the globalized food industry, whereas attempts to validate the overall method and the isoscapes upon which they are based, generally require the use of modern individuals (with known origins).

Several avenues for future research to address these concerns can be proposed. As the method and approach works similarly for humans as for other terrestrial animals, validating the approach using isotope values from modern fauna may represent an ideal sampling approach that avoids the complications of the consumption of imported food, if samples are taken from wild or captive animals with known dietary histories. Another possibility would be to focus on (archaeological) individuals of known origins who pre-date the recent rapid expansion of the global food economy, for example from pre-20th century or other historical contexts. In the context of the broader aims of this volume (promises and impasses in digital archaeology), we conclude that the combined isotope/isoscape method still holds much potential for provenance investigations more generally, and for constraining the natal origins of individuals in archaeological research more specifically. The current study, however, clearly indicates that caution is merited when applying isotopes and isoscapes to assess geographic origins in modern and forensic cases, at least within the study area of the Circum-Caribbean. The consumption of large quantities of non-local foods violates one of the main underlying principles of the isotope method, namely that isotope values of biogenic tissues will reflect the local environment. We suggest that more research is required, particularly systematic validation tests of multiple isotopes systems and multiple isoscapes, within the Caribbean and beyond, in order to assess the reliability of these methods for investigations of geographic origins before they can be more widely and effectively applied in archaeological and forensic research.

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REFERENCES

- Adams, S., R. Grün, D. McGahan, J. Zhao, Y. Feng, A. Nguyen, M. Willmes, M. Quaresimin, B. Lobsey, M. Collard, and M. C. Westaway. 2019. "A strontium isoscape of north-east Australia for human provenance and repatriation." *Geoarchaeology* 34, 3: 231-251. DOI:10.1002/gea.21728.
- AlQahtani, S.J., M.P. Hector, and H.M. Liversidge. 2010. "Brief communication: The London atlas of human tooth development and eruption." *American Journal of physical anthropology* 142, 3: 481-490. DOI:10.1002/ajpa.21258.
- Ammer, S.T.M., L.M. Kootker, E.J. Bartelink, B.E. Anderson, E. Cunha, and G.R. Davies. 2020. "Comparison of strontium isotope ratios in Mexican human hair and tap water as provenance indicators." *Forensic Science International* 314: 110422. DOI:10.1016/j.forsciint.2020.110422.
- Bartelink, E.J., L.A. Chesson, B.J. Tipple, S. Hall, and R. T. Kramer. 2020. "Multi-isotope approaches for region-of-origin predictions of undocumented border crossers from the US – Mexico border: Biocultural perspectives on diet and travel history." *Forensic Science and Humanitarian Action: Interacting with the Dead and the Living*: 369-384.
- Bataille, C.P., and G.J. Bowen. 2012. "Mapping ⁸⁷Sr/⁸⁶Sr variations in bedrock and water for large scale provenance studies." *Chemical Geology* 304: 39-52. DOI:10.1016/j.chemgeo.2012.01.028.
- Bataille, C.P., B.E. Crowley, M.J. Wooller, and G.J. Bowen. 2020. "Advances in global bioavailable strontium isoscapes." *Palaeogeography, Palaeoclimatology, Palaeoecology* 555: 109849. DOI:10.1016/j.palaeo.2020.109849.
- Bataille, C.P., I.C.C von Holstein, J.E. Laffoon, M. Willmes, X. Liu, and G.R. Davies. 2018. "A bioavailable strontium isoscape for Western Europe: A machine learning approach." *PLoS one* 13, 5: e0197386. DOI:10.1371/journal.pone.0197386.
- Bataille, C.P., K. Jaouen, S. Milano, M. Trost, S. Steinbrenner, É. Crubézy, and R. Colleter. 2021. "Triple sulfur-oxygen-strontium isotopes probabilistic geographic assignment of archaeological remains using a novel sulfur isoscape of western Europe." *PLoS One* 16, 5: e0250383. DOI:10.1371/journal.pone.0250383.
- Bataille, C.P., J.Laffoon, and G.J. Bowen. 2012. "Mapping multiple source effects on the strontium isotopic signatures of ecosystems from the circum-Caribbean region." *Ecosphere* 3, 12: 1-24. DOI:10.1890/ES12-00155.1.
- Bentley, R.A. 2006. "Strontium isotopes from the earth to the archaeological skeleton: a review." *Journal of archaeological method and theory* 13, 2006: 135-187. DOI:10.1007/s10816-006-9009-x.
- Bowen, G.J. 2010. "Isoscapes: spatial pattern in isotopic biogeochemistry." *Annual review of earth and planetary sciences* 38: 161-187. DOI:10.1146/annurev-earth-040809-152429.
- Bowen, G.J., and B. Wilkinson. 2002. "Spatial distribution of $\delta^{18}\text{O}$ in meteoric precipitation." *Geology* 30, no. 4: 315-318. DOI:10.1130/0091-7613(2002)030%3C0315:SDOIM%3E2.0.CO;2.
- Brettell, R., J. Montgomery, and J. Evans. 2012. "Brewing and stewing: the effect of culturally mediated behaviour on the oxygen isotope composition of ingested fluids and the implications for human provenance studies." *Journal of Analytical Atomic Spectrometry* 27, no. 5: 778-785. DOI:10.1039/c2ja10335d.
- Britton, K., M. Le Corre, M. Willmes, I. Moffat, R. Grün, M.A. Mannino, S. Woodward, and K. Jaouen. 2020. "Sampling plants and malacofauna in ⁸⁷Sr/⁸⁶Sr bioavailability studies: Implications for isoscape mapping and reconstructing of past mobility patterns." *Frontiers in Ecology and Evolution* 8: 579473. DOI:10.3389/fevo.2020.579473.
- Budd, P., J. Montgomery, B. Barreiro, and R.G. Thomas. 2000. "Differential diagenesis of strontium in archaeological human dental tissues." *Applied geochemistry* 15, 5: 687-694. DOI:10.1016/S0883-2927(99)00069-4.
- Chenery, C.A., V. Pashley, A.L. Lamb, H.J. Sloane, and J.A. Evans. 2012. "The oxygen isotope relationship between the phosphate and structural carbonate fractions of human bioapatite." *Rapid Communications in Mass Spectrometry* 26, 3: 309-319. DOI:10.1002/rcm.5331.
- Chesson, L.A., and G.E. Berg. 2021. "The use of stable isotopes in postconflict forensic identification." *Wiley Interdisciplinary Reviews: Forensic Science* 4, 2: e1439. DOI:10.1002/wfs2.1439.
- Chesson, L.A., B.J. Tipple, J.R. Ehleringer, T. Park, and E.J. Bartelink. 2018. "Forensic applications of isotope landscapes ("isoscapes") A tool for predicting region-of-origin in forensic anthropology cases." *Forensic anthropology: theoretical framework and scientific basis*: 127-148.
- Colleter, R., C.P. Bataille, H. Dabernat, D. Pichot, P. Hamon, S. Duchesne, F. Labaune-Jean, S. Jean, G. Le Cloirec, S. Milano, M. Trost, S. Steinbrenner, M. Marchal, C. Guilbeau-Frugier, N. Telmon, É.

- Crubézy, and K. Jaouen. 2021. "The last battle of Anne of Brittany: Solving mass grave through an interdisciplinary approach (paleopathology, biological anthropology, history, multiple isotopes and radiocarbon dating)." *PLoS One* 16, 5: e0248086. DOI:10.1371/journal.pone.0248086.
- Coplen, T.B. 1988. "Normalization of oxygen and hydrogen isotope data." *Chemical Geology: Isotope Geoscience Section* 72, no. 4: 293-297. DOI:10.1016/0168-9622(88)90042-5.
- Dansgaard, W. 1964. "Stable isotopes in precipitation." *Tellus* 16, 4: 436-468. DOI:10.3402/tellusa.v16i4.8993.
- Daux, V., C. Lécuyer, M. Hérán, R. Amiot, L. Simon, F. Fourel, F. Martineau, N. Lynnerup, H. Reyhler, and G. Escarguel. 2008. "Oxygen isotope fractionation between human phosphate and water revisited." *Journal of human evolution* 55, 6: 1138-1147. DOI:10.1016/j.jhevol.2008.06.006.
- Ehleringer, J.R., A.H. Thompson, D.W. Podlesak, G.J. Bowen, L.A. Chesson, T.E. Cerling, T. Park, P. Dostie, and H. Schwarcz. 2010. "A framework for the incorporation of isotopes and isoscapes in geospatial forensic investigations." *Isoscapes: Understanding movement, pattern, and process on earth through isotope mapping*: 357-387. DOI:10.1007/978-90-481-3354-3_17.
- Ericson, J.E. 1985. "Strontium isotope characterization in the study of prehistoric human ecology." *Journal of human evolution* 14, 5: 503-514. DOI:10.1016/S0047-2484(85)80029-4.
- Evans, J.A., J. Montgomery, G. Wildman, and N. Boulton. 2010. "Spatial variations in biosphere $87\text{Sr}/86\text{Sr}$ in Britain." *Journal of the geological society* 167, 1: 1-4.
- Faure, G., and T.M. Mensing. 2005. *Isotopes: principles and applications*. Hoboken, N.J.: John Wiley & Sons, Inc.
- Font, L., G. Jonker, P.A. van Aalderen, E.F. Schiltmans, and G.R. Davies. 2015. "Provenancing of unidentified World War II casualties: Application of strontium and oxygen isotope analysis in tooth enamel." *Science & Justice* 55, 1: 10-17. DOI:10.1016/j.scijus.2014.02.005.
- Font, L., G. Van Der Peijl, C. Van Leuwen, I. Van Wetten, and G.R. Davies. 2015. "Identification of the geographical place of origin of an unidentified individual by multi-isotope analysis." *Science & Justice* 55, 1: 34-42. DOI:10.1016/j.scijus.2014.06.011.
- Fricke, H.C., J.R. O'Neil, and N. Lynnerup. 1995. "Oxygen isotope composition of human tooth enamel from medieval Greenland: linking climate and society." *Geology* 23, 10: 869-872.
- Funck, J., C. Bataille, J. Rasic, and M. Wooller. 2021. "A bio-available strontium isoscape for eastern Beringia: a tool for tracking landscape use of Pleistocene megafauna." *Journal of Quaternary Science* 36, 1: 76-90. DOI:10.1002/jqs.3262.
- Galimov, E.M., V.S. Sevastyanov, E.V. Kulbachevskaya, and A.A. Golyavin. 2005. "Isotope ratio mass spectrometry: $\delta^{13}\text{C}$ and $\delta^{15}\text{N}$ analysis for tracing the origin of illicit drugs." *Rapid Communications in Mass Spectrometry* 19, 10: 1213-1216. DOI:10.1002/rcm.1896.
- Gat, J.R. 1996. "Oxygen and hydrogen isotopes in the hydrologic cycle." *Annual Review of Earth and Planetary Sciences* 24, 1: 225-262. DOI:10.1146/annurev.earth.24.1.225.
- Giovas, C.M., G.D. Kamenov, S.M. Fitzpatrick, and J.Krigbaum. 2016. "Sr and Pb isotopic investigation of mammal introductions: Pre-Columbian zoogeographic records from the Lesser Antilles, West Indies." *Journal of Archaeological Science* 69: 39-53. DOI:10.1016/j.jas.2016.03.006.
- Giovas, C.M., G.D. Kamenov, and J. Krigbaum. 2019. " $^{87}\text{Sr}/^{86}\text{Sr}$ and ^{14}C evidence for peccary (Tayassuidae) introduction challenges accepted historical interpretation of the 1657 Ligon map of Barbados." *PloS one* 14, 5: e0216458. DOI:10.1371/journal.pone.0216458.
- Grimstead, D.N., S. Nugent, and J. Whipple. 2017. "Why a standardization of strontium isotope baseline environmental data is needed and recommendations for methodology." *Advances in Archaeological Practice* 5, 2: 184-195. DOI:10.1017/aap.2017.6.
- Hedman, K.M., P.A. Slater, M.A. Fort, T.E. Emerson, and J.M. Lambert. 2018. "Expanding the strontium isoscape for the American midcontinent: Identifying potential places of origin for Cahokian and Pre-Columbian migrants." *Journal of Archaeological Science: Reports* 22: 202-213. DOI:10.1016/j.jasrep.2018.09.027.
- Hillson, S. 1996. *Dental anthropology*. Cambridge: Cambridge University Press.
- Hobson, K.A., R. Barnett-Johnson, and T. Cerling. 2010. "Using isoscapes to track animal migration." *Isoscapes: Understanding movement, pattern, and process on Earth through isotope mapping*: 273-298. DOI:10.1007/978-90-481-3354-3_13.
- Hobson K.A. and L. Wassenaar. 2019. *Tracking Animal Migration with Stable Isotopes*. London United Kingdom: Academic Press/Elsevier.
- Hobson, K.A., S.L. Van Wilgenburg, L.I. Wassenaar, R.L. Powell, C.J. Still, and J.M. Craine. 2012. "A multi-

- isotope ($\delta^{13}\text{C}$, $\delta^{15}\text{N}$, $\delta^2\text{H}$) feather isoscape to assign Afrotropical migrant birds to origins.” *Ecosphere* 3, 5: 1-20. DOI: 10.1890/ES12-00018.1.
- Hodell, D.A., R.L. Quinn, M. Brenner, and G. Kamenov. 2004. “Spatial variation of strontium isotopes ($^{87}\text{Sr}/^{86}\text{Sr}$) in the Maya region: a tool for tracking ancient human migration.” *Journal of Archaeological Science* 31, 5: 585-601. DOI: 10.1016/j.jas.2003.10.009.
- Hoppe, K.A., P.L. Koch, and T.T. Furutani. 2003. “Assessing the preservation of biogenic strontium in fossil bones and tooth enamel.” *International Journal of Osteoarchaeology* 13, 1-2: 20-28. DOI: 10.1002/oa.663.
- IAEA/WMO. 2016. “Global network of isotopes in precipitation.” *The GNIP Database*. <http://www.iaea.org/water>.
- International Atomic Energy Agency. 2013. “RCWIP (Regionalized Cluster-Based Water Isotope Prediction) Model-gridded precipitation $\delta^{18}\text{O}$ and $\delta^2\text{H}$ isoscape data.” International Atomic Energy Agency, Vienna, Austria. <http://www.iaea.org/water>.
- Kamenov, G.D., and J.H. Curtis. 2017. “Using carbon, oxygen, strontium, and lead isotopes in modern human teeth for forensic investigations: a critical overview based on data from Bulgaria.” *Journal of forensic sciences* 62, 6: 1452-1459. DOI: 10.1111/1556-4029.13462.
- Kootker, L.M., E. Plomp, S.T.M. Ammer, V. Hoogland, and G.R. Davies. 2020. “Spatial patterns in $^{87}\text{Sr}/^{86}\text{Sr}$ ratios in modern human dental enamel and tap water from the Netherlands: implications for forensic provenancing.” *Science of the Total Environment* 729: 138992. DOI: 10.1016/j.scitotenv.2020.138992.
- Kramer, R.T., E.J. Bartelink, N.P. Herrmann, C.P. Bataille, and K. Spradley. 2020. “Application of stable isotopes and geostatistics to infer region of geographical origin for deceased undocumented Latin American migrants.” *Forensic Science and Humanitarian Action: Interacting with the Dead and the Living*: 425-440.
- Laffoon, J.E. 2012. “Patterns of paleomobility in the ancient Antilles: an isotopic approach.” PhD diss., Leiden University. <https://hdl.handle.net/1887/20072>.
- Laffoon, J.E., Y. Chinique de Armas. 2022. “Investigating Variability in Indigenous Lifeways in the Pre-Colonial Greater Antilles: New multiple isotope results from Cuba”. Proceedings of the 29th Congress of the International Association for Caribbean Archaeology.
- Laffoon, J.E., G.R. Davies, M.L.P. Hoogland, and C.L. Hofman. 2012. “Spatial variation of biologically available strontium isotopes ($^{87}\text{Sr}/^{86}\text{Sr}$) in an archipelagic setting: a case study from the Caribbean.” *Journal of Archaeological Science* 39, 7: 2371-2384. DOI: 10.1016/j.jas.2012.02.002.
- Laffoon, J.E., M.L.P. Hoogland, G.R. Davies, and C.L. Hofman. 2019. “A multi-isotope investigation of human and dog mobility and diet in the pre-colonial Antilles.” *Environmental Archaeology* 24, 2: 132-148. DOI: 10.1080/14614103.2017.1322831.
- Laffoon, J.E., R. Rodríguez Ramos, L. Chanlatte Baik, Y. Narganes Storde, M. Rodríguez Lopez, G.R. Davies, and C.L. Hofman. 2014. “Long-distance exchange in the precolonial Circum-Caribbean: A multi-isotope study of animal tooth pendants from Puerto Rico.” *Journal of Anthropological Archaeology* 35: 220-233. DOI: 10.1016/j.jaa.2014.06.004.
- Laffoon, J.E., T.F. Sonnemann, M.M. Antczak, and A. Antczak. 2018. “Sourcing nonnative mammal remains from Dos Mosquises Island, Venezuela: new multiple isotope evidence.” *Archaeological and Anthropological Sciences* 10: 1265-1281. DOI: 10.1007/s12520-016-0453-6.
- Laffoon, J.E., T.F. Sonnemann, T. Shafie, C.L. Hofman, U. Brandes, and G.R. Davies. 2017. “Investigating human geographic origins using dual-isotope ($^{87}\text{Sr}/^{86}\text{Sr}$, $\delta^{18}\text{O}$) assignment approaches.” *PloS one* 12, 2: e0172562. DOI: 10.1371/journal.pone.0172562.
- Laffoon, J.E., R. Valcárcel Rojas, and C.L. Hofman. 2013. “Oxygen and carbon isotope analysis of human dental enamel from the Caribbean: implications for investigating individual origins.” *Archaeometry* 55, 4: 742-765. DOI: 10.1111/j.1475-4754.2012.00698.x.
- Lee-Thorp, J.A. 2008. “On isotopes and old bones.” *Archaeometry* 50, 6: 925-950. DOI: 10.1111/j.1475-4754.2008.00441.x.
- Lehn, C., A. Rossmann, and M. Graw. 2015. “Provenancing of unidentified corpses by stable isotope techniques – presentation of case studies.” *Science & Justice* 55, 1: 72-88. DOI: 10.1016/j.scijus.2014.10.006.
- Lin, G.P., Y.H. Rau, Y.F. Chen, C.C. Chou, and W.G. Fu. 2003. “Measurements of δD and $\delta^{18}\text{O}$ stable isotope ratios in milk.” *Journal of Food Science* 68, 7: 2192-2195. DOI: 10.1111/j.1365-2621.2003.tb05745.x.
- Longinelli, A. 1984. “Oxygen isotopes in mammal bone phosphate: a new tool for paleohydrological and paleoclimatological research?” *Geochimica et cosmochimica Acta* 48, 2: 385-390. DOI: 10.1016/0016-7037(84)90259-X.
- Lugli, F., A. Cipriani, L. Bruno, F. Ronchetti, C. Cavazzuti, and S. Benazzi. 2022. “A strontium isoscape of Italy for provenance studies.” *Chemical Geology* 587: 120624. DOI: 10.1016/j.chemgeo.2021.120624.

- Luz, B., Y. Kolodny, and M. Horowitz. 1984. "Fractionation of oxygen isotopes between mammalian bone-phosphate and environmental drinking water." *Geochimica et Cosmochimica Acta* 48, 8: 1689-1693. DOI:10.1016/0016-7037(84)90338-7.
- Makarewicz, C.A., and J. Sealy. 2015. "Dietary reconstruction, mobility, and the analysis of ancient skeletal tissues: expanding the prospects of stable isotope research in archaeology." *Journal of archaeological science* 56: 146-158. DOI:10.1016/j.jas.2015.02.035.
- Mehl, A.C.S.B., L. Yumi Ishida, and R. Alexandre de Faria. 2019. "Analysis of Carbon, Oxygen, Strontium and Lead Isotopes in Human Teeth: Inferences for Forensic Investigation." In *XXVI Brazilian Congress on Biomedical Engineering: CBEB 2018, Armação de Buzios, RJ, Brazil, 21-25 October 2018 (Vol. 1)*: 71-77. Singapore: Springer. DOI:10.1007/978-981-13-2119-1_11.
- Meier-Augenstein, W., and I. Fraser. 2008. "Forensic isotope analysis leads to identification of a mutilated murder victim." *Science & Justice* 48, 3: 153-159. DOI:10.1016/j.scijus.2007.10.010.
- Mickleburgh, H.L., J.E. Laffoon, J.R. Pagán Jiménez, A.A.A. Mol, S. Walters, Z.J.M. Beier, and C.L. Hofman. 2019. "Precolonial/early colonial human burials from the site of White Marl, Jamaica: New findings from recent rescue excavations." *International Journal of Osteoarchaeology* 29, 1: 155-161. DOI:10.1002/oa.2707.
- Nelson, B.K., M.J. DeNiro, M.J. Schoeninger, D.J. De Paolo, and P.E. Hare. 1986. "Effects of diagenesis on strontium, carbon, nitrogen and oxygen concentration and isotopic composition of bone." *Geochimica et Cosmochimica Acta* 50, 9: 1941-1949. DOI:10.1016/0016-7037(86)90250-4.
- Ostapkowicz, J., F. Brock, A.C. Wiedenhoeft, C. Snoeck, J. Pouncett, Y. Baksh-Comeau, R. Schulting, P. Claeys, N. Mattielli, M. Richards, and A. Boomert. 2017. "Black pitch, carved histories: radiocarbon dating, wood species identification and strontium isotope analysis of prehistoric wood carvings from Trinidad's Pitch Lake." *Journal of Archaeological Science: Reports* 16: 341-358. DOI:10.1016/j.jasrep.2017.08.018.
- Pederzani, S., and K. Britton. 2019. "Oxygen isotopes in bioarchaeology: Principles and applications, challenges and opportunities." *Earth-Science Reviews* 188: 77-107. DOI:10.1016/j.earscirev.2018.11.005.
- Pestle, W.J., A. Simonetti, and L.A. Curet. 2013. "⁸⁷Sr/⁸⁶Sr variability in Puerto Rico: geological complexity and the study of paleomobility." *Journal of Archaeological Science* 40, 5: 2561-2569. DOI:10.1016/j.jas.2013.01.020.
- Plomp, E., I.C.C. von Holstein, J.M. Koornneef, R.J. Smeets, J.A. Baart, T. Forouzanfar, and G.R. Davies. 2019. "Evaluation of neodymium isotope analysis of human dental enamel as a provenance indicator using 10¹³ Ω amplifiers (TIMS)." *Science & Justice* 59, 3: 322-331. DOI:10.1002/ajpa.24059.
- Plomp, E., I.C.C. von Holstein, L.M. Kootker, S.J.A. Verdegaal-Warmerdam, T. Forouzanfar, and G.R. Davies. 2020. "Strontium, oxygen, and carbon isotope variation in modern human dental enamel." *American Journal of Physical Anthropology* 172, 4: 586-604. DOI:10.1016/j.scijus.2019.02.001.
- Podlesak, D.W., A. Torregrossa, J.R. Ehleringer, M.D. Dearing, B.H. Passey, and T.E. Cerling. 2008. "Turnover of oxygen and hydrogen isotopes in the body water, CO₂, hair, and enamel of a small mammal." *Geochimica et Cosmochimica Acta* 72, 1: 19-35. DOI:10.1016/j.gca.2007.10.003.
- Price, T.D. 1989. "Multi-element studies of diagenesis in prehistoric bone." *The chemistry of prehistoric human bone*: 126-154.
- Price, T.D., J.H. Burton, and R. A. Bentley. 2002. "The characterization of biologically available strontium isotope ratios for the study of prehistoric migration." *Archaeometry* 44, 1: 117-135. DOI:10.1111/1475-4754.00047.
- Price, T.D., J.H. Burton, and J.B. Stoltman. 2007. "Place of origin of prehistoric inhabitants of Aztalan, Jefferson Co., Wisconsin." *American Antiquity* 72, 3: 524-538. DOI:10.2307/40035859.
- Scaffidi, B.K., and K.J. Knudson. 2020. "An archaeological strontium isoscape for the prehistoric Andes: Understanding population mobility through a geostatistical meta-analysis of archaeological ⁸⁷Sr/⁸⁶Sr values from humans, animals, and artifacts." *Journal of Archaeological Science* 117: 105121. DOI:10.1016/j.jas.2020.105121.
- Schellenberg, A., S. Chmielus, C. Schlicht, F. Camin, M. Perini, L. Bontempo, K. Heinrich, S.D. Kelly, A. Rossmann, F. Thomas, E. Jamin, and M. Horacek. 2010. "Multielement stable isotope ratios (H, C, N, S) of honey from different European regions." *Food chemistry* 121, 3: 770-777. DOI:10.1016/j.foodchem.2009.12.082.
- Schulting, R., M. Richards, J. Pouncett, B. Naqqi Manco, E. Freid, and J. Ostapkowicz. 2018. "Absence of Saharan dust influence on the strontium isotope ratios on modern trees from the Bahamas and

- Turks and Caicos Islands.” *Quaternary Research* 89, 2: 394-412. DOI:10.1017/qua.2018.8.
- Schwarcz, H.P., L. Gibbs, and M. Knyf. 1991. “Oxygen isotope analysis as an indicator of place of origin.” In *Snake Hill: An Investigation of a Military Cemetery from the War of 1812*, edited by S. Pfeiffer and R. Williamson: 263-268. Toronto: Dundurn.
- Sealy, J.C., N.J. van der Merwe, A. Sillen, F.J. Kruger, and H.W. Krueger. 1991. “ $^{87}\text{Sr}/^{86}\text{Sr}$ as a dietary indicator in modern and archaeological bone.” *Journal of Archaeological Science* 18, 3: 399-416. DOI: 10.1016/0305-4403(91)90074-Y.
- Sharpe, A.E., N. Smith-Guzmán, J. Curtis, I. Isaza-Aizpurúa, G.D. Kamenov, T.A. Wake, and R.G. Cooke. 2021. “A preliminary multi-isotope assessment of human mobility and diet in pre-Columbian Panama.” *Journal of Archaeological Science: Reports* 36: 102876. DOI:10.1016/j.jasrep.2021.102876.
- Snoeck, C., J. Pouncett, P. Claeys, S. Goderis, N. Mattielli, M. Parker Pearson, C. Willis, A. Zazzo, J.A. Lee-Thorp, and R.J. Schulting. 2018. “Strontium isotope analysis on cremated human remains from Stonehenge support links with west Wales.” *Scientific reports* 8, 1: 10790. DOI:10.1038/s41598-018-28969-8.
- Terzer, S., L.I. Wassenaar, L.J. Araguás-Araguás, and P.K. Aggarwal. 2013. “Global isoscapes for $\delta^{18}\text{O}$ and $\delta^2\text{H}$ in precipitation: improved prediction using regionalized climatic regression models.” *Hydrology and Earth System Sciences* 17, 11: 4713-4728. DOI:10.5194/hess-17-4713-2013.
- Trickett, M.A., P. Budd, J. Montgomery, and J. Evans. 2003. “An assessment of solubility profiling as a decontamination procedure for the $^{87}\text{Sr}/^{86}\text{Sr}$ analysis of archaeological human skeletal tissue.” *Applied Geochemistry* 18, 5: 653-658. DOI:10.1016/S0883-2927(02)00181-6.
- Ueda, M., and L.S. Bell. 2021. “Assessing the predictability of existing water-to-enamel geolocation models against known human teeth.” *Scientific Reports* 11, 1: 15645. DOI:10.1038/s41598-021-95153-w.
- Valentine, B., G.D. Kamenov, J.M. Kenoyer, V. Shinde, V. Mushrif-Tripathy, E. Otarola-Castillo, and J. Krigbaum. 2015. “Evidence for patterns of selective urban migration in the Greater Indus Valley (2600-1900 BC): a lead and strontium isotope mortuary analysis.” *PLoS One* 10, 4: e0123103. DOI:10.1371/journal.pone.0123103.
- Van der Merwe, N.J., J.A. Lee-Thorp, J.F. Thackeray, A. Hall-Martin, F.J. Kruger, H. Coetzee, R.H.V. Bell, and M. Lindeque. 1990. “Source-area determination of elephant ivory by isotopic analysis.” *Nature* 346, 6286: 744-746. DOI:10.1038/346744a0.
- West, J.B., G.J. Bowen, T.E. Dawson, and K.P. Tu. 2010. *Isoscapes: understanding movement, pattern, and process on Earth through isotope mapping*. Dordrecht: Springer Science & Business Media. DOI:10.1007/978-90-481-3354-3.
- Wright, L.E. 2005. “Identifying immigrants to Tikal, Guatemala: defining local variability in strontium isotope ratios of human tooth enamel.” *Journal of Archaeological Science* 32, 4: 555-566. DOI:10.1016/j.jas.2004.11.011.

IN MEMORIAM DAMIAN EVANS

After submitting this chapter, we learned with deep sadness of the passing of our friend and colleague, Damian Evans, on September 12, 2023, after a two-year fight and a brief remission.

Damian was renowned for his pioneering work as an archaeologist, notably spearheading the groundbreaking 2012 Lidar acquisition at Angkor. This endeavour revealed a wealth of hidden archaeological marvels concealed beneath the dense Cambodian jungle canopy, illuminating ancient Angkor's intricate urban complexity and extensive infrastructure.

Fitting with the title of our paper in this volume, Damian proved himself as a remarkable figure in both the untamed jungles of Southeast Asia and the lab. He established labs in Laos, Paris, and Cambodia dedicated to the meticulous analysis of lidar data, generously opening their doors to anyone studying in the region. He also established a framework for working with lidar data, championing its sharing and open access. Damian's innovative spirit blazed a trail for future researchers pioneering the integration of AI techniques with lidar data. But he was happiest when riding his dirt bike through rugged terrain or getting his truck stuck in the mud on the way to a field site. Ever ready for unforeseen challenges, he armed himself with an array of medications to combat any field-induced illness that may afflict our team. His unwavering commitment to his work in challenging environments showcased his resilience and adventurous spirit.

His passing has been marked by tearful reminiscences and heartfelt tributes, a testament to the deep friendships that emerge through fieldwork. Our colleague, Mitch Hendrickson, said it well: "The crucible in which our friendships with Damian were forged left a much deeper impact than other types of relationships. The result is that he will be an important part of us forever."

Sarah Klassen and Tommaso Pappagallo



From the Jungle to the Lab: Using Remote-Sensing and Deep Learning to Map Archaeological Features in Lab-based Settings

Sarah Klassen, Tommaso Pappagallo
and Damian Evans

1 INTRODUCTION

Advances in remote sensing have dramatically improved the ability of archaeologists to identify and map archaeological sites (Lasaponara and Masini 2011; Masini *et al.* 2011; Opitz 2013). Instead of venturing in frequently exploratory ways into inhospitable jungles and arid landscapes that were once home to thriving civilizations, archaeologists find themselves at desks behind computer screens, poring over terabytes of remotely sensed data and pinpointing places to visit in the field. Mapping and survey work that once required days or weeks in the field can be achieved, at least in a preliminary way, by a desk-based digital workflow incorporating archives of satellite imagery and aerial photography.

While archaeologists have been able to identify untold thousands of archaeological features using these 2D, image-based approaches, many features are obscured from view because of dense vegetation. With the advent of airborne laser ranging (lidar) over vast areas, archaeologists now can represent the landscape in a 3D form based on distance calculations determined by the amount of time required for the laser pulses to return to the airborne sensor from reflective surfaces on the landscape below. Within the dense point clouds that are thus generated, archaeologists have been able to identify points that represent features above the surface such as vegetation, algorithmically remove those points, and produce digital elevation models of the bare earth. These models have proved invaluable for identifying archaeological features that previously laid hidden below the dense vegetation and achieving in hours what once took years using ground-based measurements.

Faced with these massive amounts of data, archaeologists have two tasks: 1) Identify and inventory archaeological features; and 2) create maps representing these archaeological features. Thanks to wide-area, georeferenced digital imagery, both of these tasks are being undertaken on previously unimaginable scales. In addition to the vast archives of geospatial imagery, archaeologists are generating derivative data products on a massive scale. Some have referred to this influx of data as the "data deluge" (Bevan 2015) and have argued that a paradigm shift is required for archaeologists to take advantage of the avenues of research now available with the new data (Bennet 2014). As a result, many archaeologists have turned to deep-learning methods (LeCun *et al.* 2015) to help identify, map, and analyze these newly identified archaeological sites and features (see below).

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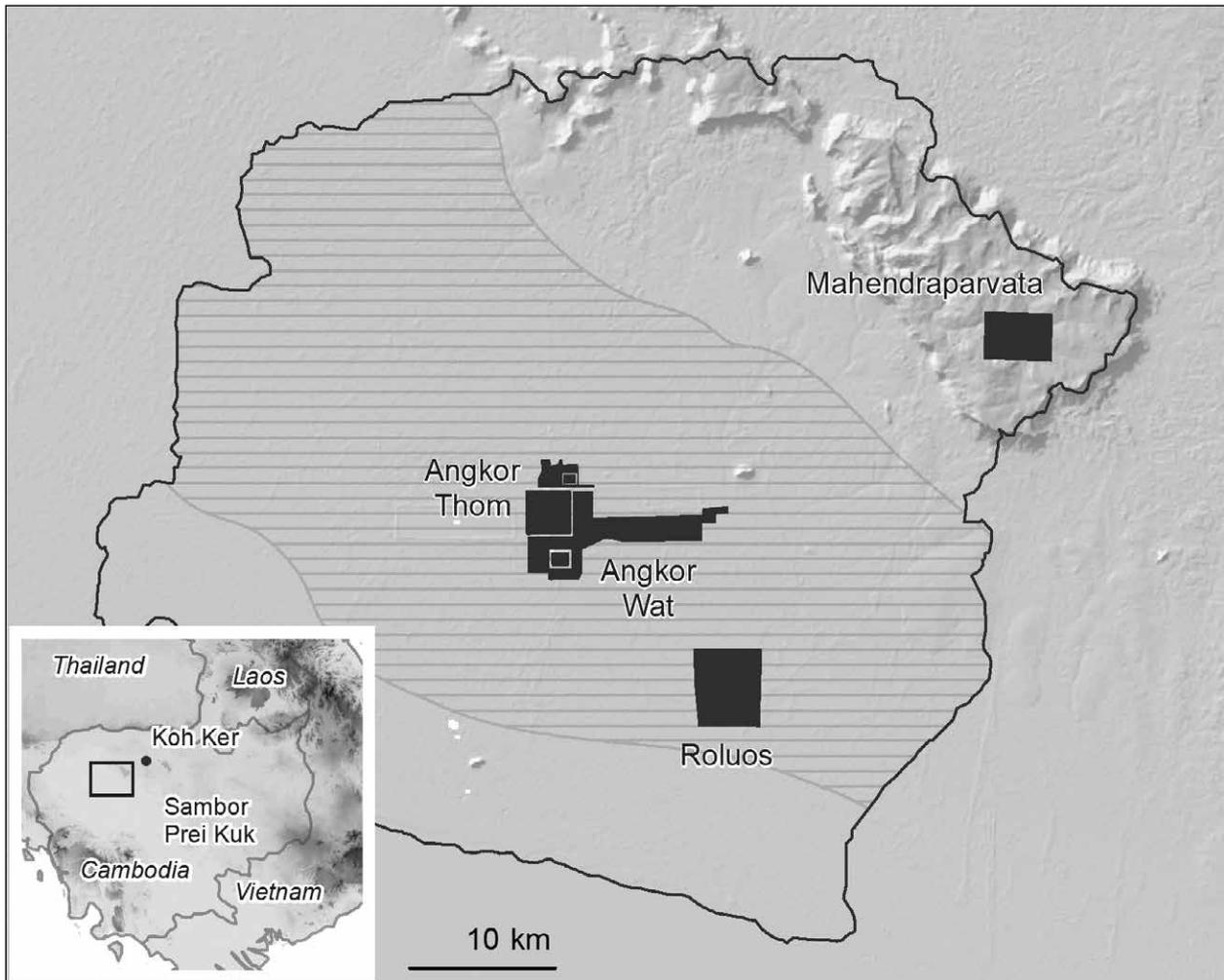


Figure 1: The Greater Angkor Region (~3000 km²) encompasses over 1500 km² of agricultural land (AMA) and densely occupied urban spaces (CCC).

In this paper, we first introduce the Khmer Archaeological LiDAR Consortium (KALC) and the Cambodian Archaeological Lidar Initiative (CALI). We then survey the literature for automated detection of features in 2D and 3D remote sensing data and canvas the application of these techniques to archaeological case studies. We outline the processes undertaken by KALC and CALI and highlight some of the challenges and opportunities offered by using automated methods to identify archaeological features across a range of projects. Finally, we conclude with some thoughts for the future of remote sensing and automatic detection of features for archaeology.

2 BACKGROUND TO THE KHMER ARCHAEOLOGICAL LiDAR CONSORTIUM (KALC) AND THE CAMBODIAN ARCHAEOLOGICAL LIDAR INITIATIVE RESULTS (CALI): SUCCESSES AND BOTTLENECKS

The Greater Angkor Region is home to a large medieval archaeological site known as Angkor (figure 1). Our study area of over 3000 km² encompasses an engineered landscape of over 1500 km² consisting of a mix of agricultural land and densely occupied urban spaces in which a series of massive temples, including Angkor Wat, were built over centuries (Stark 2004). The agricultural areas are often referred to as the Angkor Metropolitan Area (AMA), while the densely occupied urban spaces are



Figure 2: The AMA is characterized by community temples recognizable in satellite imagery because of their distinctive horseshoe-shaped morphologies.

often called Civic-Ceremonial Centers (CCCs) (Carter *et al.* 2021; Hawken 2011; Klassen *et al.* 2021).

The AMA is characterized by small agricultural units consisting of community temples and associated occupation mounds and reservoirs. These features were interspersed among almost 1000 km² of rice fields (Hawken 2011). The configurations of temples and associated occupation mounds, reservoirs, and ricefields are often referred to as *prasat-trapeang* (temple-pond) (Klassen and Evans 2020; Sedov 1963). The medieval Khmer living in and around these communities were primarily engaged with rice agriculture, which formed an essential component

of the agrarian economy (Sedov 1963). In addition to growing rice, inscriptions indicate that populations in these villages would have engaged in several productive activities, including fishing in the reservoirs, tending to orchards and vegetable gardens, and raising livestock, including pigs and water buffalo (Jacob 1978). Communities in the AMA are easily identifiable in satellite imagery because the temples typically conform to a horseshoe shaped morphology (figure 2) and are often accompanied by a reservoir at the end of a causeway leading to the east of the temple.

The temples were built on mounded pieces of earth, surrounded by an artificial moat, and often had a

causeway to the east leading to an artificial reservoir. The moat and causeways give the temples a “horseshoe” morphology, with the mound where a temple once stood in the middle. Much of the landscape in the Greater Angkor Region is still in use for rice agriculture today. As a result, much of the dense vegetation has been cleared, and the distinct morphology of temples and reservoirs is more or less visible in aerial and satellite imagery. These characteristics enabled Evans and Pottier to map almost 1000 temple communities across the expanse of Angkor’s CCCs throughout two massive mapping initiatives, based primarily on prints of aerial photographs, that formed the basis for their PhDs (Evans 2007; Pottier 1999).

The landscape of the AMA was also extensively transformed to store and manage water (Fletcher *et al.* 2008). The medieval Khmer rerouted rivers into large, above-ground holding reservoirs called *baray*. The largest of these *barays*, the West Baray, is eight kilometers long and two kilometers wide. While archaeologists have long debated the practical versus ceremonial uses of this and similar features (Acker 1998; Bourdonneau 2003; Fukui 1999; Stott 1992), it is clear that the hydraulic infrastructure could have had religious and political importance while also providing a source of water during droughts and allowing the medieval Khmer to manage massive influxes of water to the system during the monsoons (Bourdonneau 2010; Pottier 2000). This infrastructure and a ritual temple economy also integrated the AMA with the CCCs (Hendrickson 2010; Sedov 1963; Fletcher and White 2018).

Unlike the AMA, the landscape of the CCCs is located mainly within a protected forest zone (Gaughan *et al.* 2009). As a result, the vegetation is relatively dense, making it very challenging to see archaeological features in aerial and satellite imagery and making conventional ground surveys exceptionally difficult. Around Angkor Thom, for example, archaeologists working in the field were able to identify unnatural inundations in the landscape, but it was difficult to understand the patterns that these form on a large scale, let alone across the entire Angkor site (Evans and Fletcher 2015; Stark *et al.* 2015). Surveying the whole forested area using traditional methods would have taken decades. Jacques Gaucher of the EFEO spent several years cutting survey transects through an expanse of dense vegetation representing about 25% of the forested area in the central temple zone. His work was able to provide detailed information about the archaeological

materials on the landscape, and he was able to produce a provisional map of Angkor Thom, one of Angkor’s CCCs, where he identified the outlines of an urban grid (Gaucher 2002; 2003a; 2003b; 2004; 2017).

In 2012, shortly after the first successful wide-area lidar acquisition over an archaeological site, Caracol in Belize (Chase *et al.* 2011), the Khmer Archaeological LiDAR Consortium (KALC) organized a mission of airborne laser scanning across 370 km² of northern Cambodia, including the forested areas of central Angkor and two other Angkor-period capitals, Koh Ker and Mahendraparvata. The lidar data was acquired with a Leica ALS60 laser system and 40 megapixel Leica RCD105 medium-format camera. The Leica ALS60 was capable of 200,000 laser pulses per second with up to four returns each. The single-pass lidar point densities averaged 4-5 points per square meter, with an average of two ground returns per square meter. We processed the raw point clouds and created imagery products with Terrascan software. We used ArcGIS software to create additional imagery products like digital terrain models, hillshade models, and local relief models. Our team of archaeologists manually analyzed and interpreted the landscape data and were able to identify 20,000 features that had not yet been documented and mapped by the Greater Angkor (Evans 2016; Evans and Fletcher 2015; Evans *et al.* 2013). The results were equally spectacular at Mahendraparvata, where researchers were able to identify the traces of causeways and other previously undocumented elements of urban infrastructure that remained etched on the landscape but hidden beneath dense vegetation (Chevance *et al.* 2019; Evans *et al.* 2013). The data from Koh Ker has proved extremely valuable for our understanding of the archaeological site and has allowed researchers to do in-depth studies of the water management system (Lustig *et al.* 2018; Moffat *et al.* 2020). However, it was not as valuable as the data from Angkor and Mahendraparvata for mapping additional urban features for reasons to be discussed below.

One of the reasons why lidar was so illuminating at Angkor was because the site is located in a floodplain (Kummu 2009). As a result, the medieval Khmer terraformed the landscape by building their monumental structures, like Angkor Wat, on artificial platforms up to 4 m above the natural floodplain to mitigate the potentially disastrous impacts of the annual monsoon flooding. Similarly, the Khmer built their houses on stilts on top of artificially constructed house mounds ranging from 1-2 m in height. This terraforming of the landscape makes these features

extremely visible in the lidar data, even if the buildings that once stood atop them were built of perishable materials and have long since disintegrated (Fletcher and Pottier 2002). Because the features are so apparent, KALC was able to publish the initial results from the lidar before systematic mapping and ground verification had been completed (Evans *et al.* 2013).

The nature of changes to the landscape at Angkor due to the frequent threat of flooding also explains why the lidar data from Koh Ker did not reveal as many intricate details of past occupation. Koh Ker is located at a higher elevation among gently rolling hills and did not face the same threat from the annual flooding as Angkor. As a result, the medieval Khmer living at this site built their houses either on the ground or on stilts without mounds beneath them. The lack of house mounds makes identifying the zones of occupation much more difficult. Other forms of investigation, including traditional survey and ground-penetrating radar, are required to understand occupation patterns at the site fully. This work began fifteen years ago by multiple international and local teams (Evans 2013; Mizoguchi and Nakagawa 2011; Renner 2011; Hall *et al.* 2018) and is now the focus on ongoing fieldwork by the National Authority of Preah Vihear and collaborators as part of the Koh Ker Archaeological Project (Klassen *et al.* 2022).

After poring over the lidar data, researchers associated with KALC and the Greater Angkor Project began the arduous task of documenting, ground verifying, and mapping the revealed features. While it is difficult to estimate the exact number of person-hours, Damian Evans, the project lead, spent most of the period 2012-2016 working on the data in the lab and the field alongside a core staff of two to three field researchers. Sarah Klassen dedicated four months of work to the project, followed by a year of full-time mapping work by Pelle Wijker. The mapping work was subsequently refined in the lab and the field over several years by Klassen, Wijker, Evans, and other project members. The researchers combined the latest insights from the lidar data with decades of mapping and ground verification in the region (Evans 2007; Gaucher 2004; Pottier 1999). Early versions of the additional features mapped from the lidar data were first published in 2015 (Evans and Fletcher 2015), and a revised version was published recently (Klassen *et al.* 2021). The resulting map from Mahendrapavarta was published in 2019 (Chevance *et al.* 2019), seven years after the lidar data were initially acquired. This work, recently finished in late 2021, has culminated in a new

comprehensive map of the Greater Angkor Region that includes over 20,000 new features for a total of over 25,000 mapped features.

The work has profoundly impacted our understanding of early Khmer cultures and landscapes, and the resulting maps have allowed researchers to do a wide range of previously impossible analyses. With these new maps, archaeologists can be highly precise in choosing areas to excavate. For example, archaeologists used the lidar data and resulting mapping to pinpoint specific house mounds to excavate at both Angkor Wat and Ta Prohm, which helped answer questions about how people lived and what they ate (Carter *et al.* 2018; Carter *et al.* 2019; Castillo *et al.* 2020; Heng *et al.* 2015; Stark *et al.* 2015). Researchers have also been able to refine population estimates for the region. Based on the morphology and location of the mounds, the researchers were able to use principles derived from settlements scaling to estimate total population and population densities at the site across time and space. Based on the location and type of the occupation mounds, researchers could also determine the likely occupations and activities (agricultural producers vs. non-agricultural producers) for these populations and how that changed over time (Klassen *et al.* 2021). Similarly, archaeologists have also been able to use this mapping to understand patterns of use of the agricultural landscape over time and how that was impacted by changing social institutions and institutional management (Evans 2016; Klassen and Evans 2020).

Following on the success of KALC, Evans received a grant from the European Research Council (2015 to 2020) to extend the lidar acquisitions at Angkor to several other cultural landscapes sites in Cambodia, spanning the pre-Angkorian to post-Angkorian periods. This work was undertaken within the Cambodian Archaeological Lidar Initiative (CALI) framework, with a principal acquisition in 2016 covering an area of 1910 km² (Evans 2016). Another grant from the European Research Council will fund a follow-on project from 2020-25, which aims to acquire 1000 km² of data across Southeast Asia beginning in 2022, alongside a 2021-22 acquisition in Laos spanning 4000 km² funded by the French Development Agency (AFD).

CALI's results were just as spectacular as those from Angkor (figure 4; Evans 2016). As the maps from Angkor and Mahendraparvata have proved invaluable, the researchers of CALI are now faced with the formidable task of mapping the tens of thousands of clearly visible

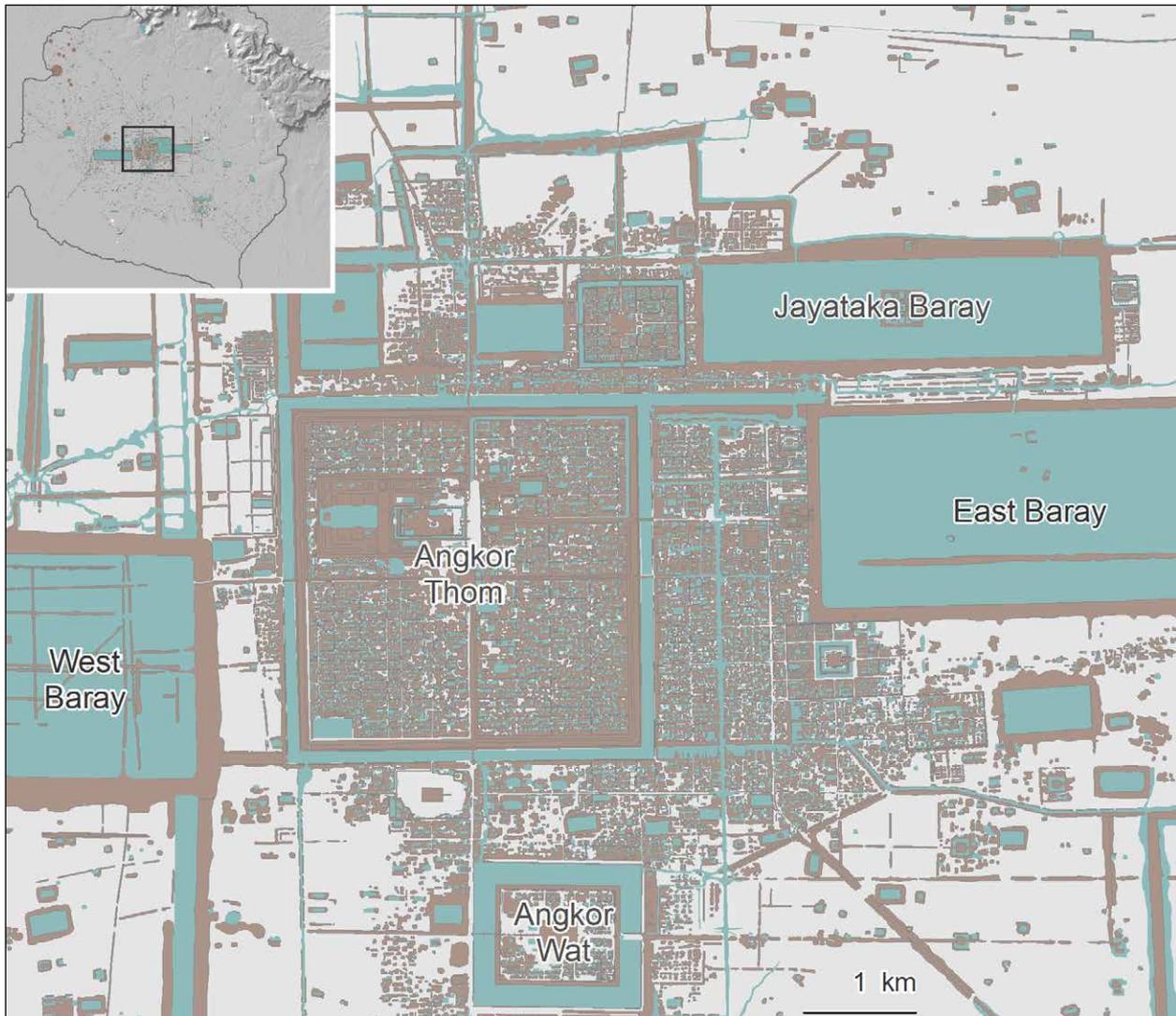


Figure 3: Map of the Greater Angkor Region.

features at these other sites in Cambodia. Work on this has been ongoing since 2015. It has involved dozens of researchers from various institutions and organizations. Many of the final results are yet to be published due to the volume of mapping and verification work required. The mapping work for CALI is now completing. As we look forward to the new lidar acquisitions in 2022, we are actively exploring automated options to help ease the burden of mapping and relieve this bottleneck.

3 A PATH FORWARD: AUTOMATED DETECTION OF FEATURES IN REMOTE SENSING DATA

In this section, we review 3D Point Cloud Deep Learning techniques. 3D point clouds are a set

of unstructured and unordered points where neighbouring points do not explicitly encode information about their relationship, unlike in 2D images, which are composed of pixels in structured arrays. This makes 3D Point Cloud Parsing a unique domain separate from 2D Imaging. We can view 3D data in its most basic form as a set of points in physical space which can be complemented with additional dimensions such as intensity and RGB colour (Demantké *et al.* 2012). Networks built for 2D have reached a more mature stage and are foundational to many 3D networks. In the same way that in 2D, we seek to assign a label to each pixel, in 3D, we strive to label each point in a point cloud. In 2D pixel parsing,



Figure 4: Lidar data from Sambor Prei Kuk. One of the sites that was surveyed as part of the Cambodian Archaeological Lidar Initiative (CALI).

the main tasks can be divided into the classification of an entire image (classification), localization and bounding box overlay of different object instances in an image (object detection), classification of single pixels into classes (segmentation), and classification of single pixels into classes and instances of the classes (instance or part segmentation). We can apply the same type of reasoning to 3D point cloud parsing.

Before the advent of Convolutional Neural Networks (CNNs), image classification was composed broadly of feature extraction and a classifier stage. Here methods can equally be divided into “pixel”

based methods and “object” based methods where the latter is a precursor to CNNs. Edge detectors, for example, looked to understand where objects were based on the location of boundaries, examining changes in the intensity of adjacent pixels. These representations of the original image sought to extract only salient information making it easier to bag the source images into classes using simple classifiers such as Support Vector Machines or Random Forests (Felzenszwalb and Huttenlocher 2004). CNNs looked to automate both processes utilizing Stochastic Gradient Descent with Backpropagation in a Fully Convolutional

Network (Qi *et al.* 2017). Here features of increasing complexity are learned since the receptive field at each layer increases, transitioning from capturing local to more contextual information. This removes the element of bias present in hand engineering features while enabling a process that can better account for the range of variability in the real world.

The classification of images paved the way for object detection networks: one-stage and two-stage detectors. The latter produce region proposals of parts of the image containing objects to be classified later using a CNN. One such is RCNN which extracts the region proposals utilizing algorithms such as Selective Search (Uijlings *et al.* 2013). RCNN uses an efficient segmentation algorithm (Felzenszwalb and Huttenlocher 2004) to obtain initial region proposals that are further refined using Hierarchical Grouping Algorithms that combine regions based on similarity. RCNN (Girshick *et al.* 2014) paved the way for Faster RCNN (Ren *et al.* 2016), where the region proposals are sourced from the feature maps directly utilizing a Region Proposal Network as well as Anchor boxes that hint at the range of scales and sizes of the objects to be identified. This development made two-stage detectors faster; however, one-stage detectors sought to further this, at the cost of accuracy, by applying classifications at different scales and aspect ratios directly to the image in one single sweep. Segmentation networks such as Mask RNN (He *et al.* 2018) build on Faster RCNN by adding a branch representing the object proposal mask which extends the loss of the class labels and bounding box offsets to include a loss representing the mask regions. To put these architectures into context, and provide some examples, Verschoof-van der Vaart and Lambers (2019) successfully used RCNN's on lidar data from the Netherlands covering an area containing several objects of archaeological interest, including prehistoric barrows and Celtic fields. Similarly, Trier *et al.* (2021) implemented Faster RCNN whilst identifying charcoal kilns, grave mounds and pitfall traps in high resolution airborne lidar data from Norway. In relation to single stage detectors, Berganzo-Besga *et al.* (2021) implemented Yolov3 in the detection of burial mounds in North-Western Iberia whilst Davis and Lundin (2021) used RetinaNet to locate Charcoal Production Sites in a forested region of Jönköping County, Sweden.

3D Point Cloud networks were initially developed similarly to 2D networks, with builds that used hand-crafted features utilizing the 3D geometric features of points from local neighbourhoods of optimal

size (Filin and Pfeifer 2005; Weinmann *et al.* 2015). Demantké *et al.* (2012), for example, looked for 3D dimensional features that indicate whether the local geometry is more linear, planar, or volumetric. The geometry hints at the type of object a set of points belongs to since different objects are varying combinations of these dimensions, suggesting how to classify and segment the points. As the labelling obtained with these methods lacked spatial smoothness, Landrieu *et al.* (2017) used the intuition that labels of neighbouring points correlated to obtain segmentations where more adjacent nodes share similar labels.

As with 2D, deep learning gave rise to 3D Point Cloud architectures which can be broadly divided into Point-based, Multi-View, and Volumetric/Voxel-based approaches. A particularly successful Point-based Method utilizing MLPs is PointNet (Qi *et al.* 2017).

PointNet is a set-based method able to consume unordered points directly, rather than discretize points as with voxel-based methods. It also differs from other networks by not using convolution operators; instead, using fully connected networks via multi-layer perceptron (MLP), PointNet uses a feature of CNNs called max pooling which makes the model invariant to permutations which are a property of the points. Additionally, to make the labelling of the points invariant to geometric transformations, another requisite, it aligns the points as well as the feature space to a canonical space before extraction using orthogonal affine transformations. By this process we can extract orthogonal (independent) features that maintain the maximal amount of information when representing features prior to our optimization. As a pipeline, it takes points as input, applies these sets of transformations, and aggregates the information utilizing the max-pooling to output a global feature vector representing the global properties of the points. This vector is passed through an MLP, which outputs scores over the different classes, classifying the entire point cloud. To allow for per-point segmentation, PointNet extends the classification network by concatenating local features with the global features to classify each point into one of the classes. However, local structural information is missed since each point extracts a feature vector independently of the other (Qi *et al.* 2017).

Point Net ++ builds on PointNet, tackling two issues of the previous iteration: not being able to consider the local structure of the points and the nonuniformity of the point density, which inevitably

affects the network's performance (Qi *et al.* 2017). The authors deal with the first point by borrowing the 2D CNNs approach of extracting features at progressively increasing scales and layers of changing resolutions. An analogue to this is built via hierarchically partitioning and grouping the points over increasing neighbourhoods to capture the gamut of information from local features, in smaller neighbourhoods, to global features in larger neighbourhoods. The original PointNet is used to extract these features. To deal with non-uniform densities, the authors implement a random drop out of the sampled points to combine the multiple scales, enabling the network to become invariant to point density.

Within Point-Based Methods, we also have convolution and graph-based approaches. Convolutional approaches borrow from 2D networks implementing a parallel of the 2D convolutional kernel, which is applied on a 2D grid structure. Here a convolutional kernel is defined in continuous 3D space where the weights of points in a neighbourhood are defined in relation to a central point – in essence, computing a weighted sum of a subset of the points. Kpconv (Thomas *et al.* 2019), for example, uses a kernel whose weights can be learned, adapting to the topology of the local geometry to gain better contextual information. Graph-based approaches consider single points as vertexes and encode their relationship to neighbouring points via edges. For example, Landrieu *et al.* (2017) implement Super Point Graphs, which partition the point cloud space into geometrically homogenous elements, an analogue of superpixels in 2D. This graph represents an ensemble of shapes rather than points which the authors argue builds a network that is better able to classify and segment entire objects and scenes instead of singular points.

Multi view-based methods try to harness the accuracy of 2D segmentation and classification networks by projecting the point cloud into 2D to perform pixel-wise labelling. For example, Boulch *et al.* (2017) generate RGB and depth images from the point cloud and then back propagate from 2D image to mesh by identifying and labelling the vertices present in the meshes. In a second instance, the mesh is backpropagated to the original point cloud, where the label of a given point $p \in P$ is the label of its nearest neighbour with a label in edge V of the mesh. These methods are seen to outperform volumetric approaches with fewer computational requirements despite being sensitive to occlusions and the choice

of viewpoints while also not taking into account underlying structures and geometries of the point cloud space. Qi *et al.* (2016) combine Multi-View and Volumetric Approaches by extracting 3D features from the point clouds using anisotropic probing kernels and projecting them into 2D space; anisotropic probing kernels are better able to capture the internal structures of objects.

Volumetric/Voxel-based approaches look to scale 2D CNNs to 3D using 3D convolutional operators. Unfortunately, due to the large number of parameters involved, volumetric methods are computationally expensive. To lower computational expenses, networks try to reduce the resolution of objects to small voxel cube grids at the cost of information loss. While segmentation approaches are possible, they are considered prohibitively expensive computationally, making them more suitable for classification tasks. To reduce the computational overhead of these networks, Riegler *et al.* (2017) suggest using a Grid Oct Tree Graph-based approach. Unlike a computational expensive vanilla oct tree, which seeks to represent each point as a child node accessible only from the root, this approach places several shallow oct trees along with regular voxel grids. In this way, the structure can be encoded efficiently via a bit string representation. Additionally, rather than convolving a 3D tensor with a 3D kernel, the network convolves onto the grid-oct tree data structure, meaning that we only need to compute the convolution once within each voxel since the output of the convolution is constant over each voxel grid.

We have explained the different families of networks utilized in Point Cloud Classification and Segmentation in broad terms, mainly Point, Multi-View, and Volumetric/Voxel-based approaches focusing on one or two important networks within each category. Not by design, we have focused on segmentation and classification approaches since there is a lack of successful object detection frameworks.

4 AUTOMATED DETECTION OF ARCHAEOLOGICAL FEATURES IN REMOTE SENSING DATA

While Cultural Heritage has been slow to use machine learning methods (Fiorucci *et al.* 2022), archaeologists have begun successfully experimenting with image classification, object detection, and segmentation to identify archaeological features in remotely sensed data (Traviglia *et al.* 2016, see more below) These methods are in addition to other machine learning methods utilized by archaeologists, like graph-based

semi-supervised machine learning algorithms to determine dates of archaeological sites (Klassen, Weed, and Evans 2018) and classification analyses to better label and understand datasets and field reports (Brandsen and Koole 2022; Brandsen *et al.* 2019).

4.1 Image classification and object detection

Researchers from the Greater Angkor Project have experimented using object detection with our archaeological lidar data sets; however, because the features are evident in the archaeological data from KALC and CALI, the object detection was not as valuable as hoped. For example, Hanus and Evans (2015) used an algorithm for semi-automatic pond detection to determine the number of house ponds within the walls of Angkor Thom. While somewhat helpful, one could argue that it would have been just as easy and more time-efficient to count the ponds manually. Similarly, because the mapping work was ongoing, the authors could compare the number of ponds derived from the algorithm to the number of ponds that had been mapped. As a result, the authors adjusted their model and thus their results to better reflect the actual number of ponds on the landscape.

While lidar-enabled archaeological research in tropical floodplains of Southeast Asia has been aided by engineering choices made over a thousand years ago to construct sustainable settlements in these flood-prone areas, other regions have not been as fortunate. For example, our colleagues working in the Maya region deal with a very different type of archaeological signature on the landscape. At Caracol, for instance, houses are identified by 10-20 cm house platforms hidden below dense vegetation and obscured in the lidar data due to the natural topographical variation. While these platforms are visible on the lidar data, primarily through various visualizations of lidar data (hillshades, slope analysis, local relief models, etc.; Chase and Chase 2017), they are much more difficult to detect than the 1-2 m house mounds in the Greater Angkor Region. As a result, researchers working in the Maya region have experimented with U-Net and Mask R-CNN models for semantic segmentation of Maya buildings. The authors found that U-Net was the most successful model and could correctly identify 60-66% of all objects and 74-81% of medium-sized objects (Bundzel *et al.* 2020). Still, others have achieved 95% classification accuracy with several variations of VGG-19 CNNs (Somrak *et al.* 2020).

Archaeologists are increasingly turning to CNNs to identify archaeological features from remotely sensed

data (Verschoof-van der Vaart and Lambers 2019; Trier *et al.* 2019; Soroush *et al.* 2020). For example, Gallwey *et al.* (2019) used CNNs trained on lidar datasets to identify indications of copper and tin mines at Dartmoor National Park, using lidar data obtained from the Environment Agency in the United Kingdom. With the CNNs, the team achieved recall rates of 80%-83% (depending on the resolution, 0.5 m and 0.25 m). Interestingly, the rate of false positives was below 20%. 20% is a reasonable amount of false positives to expect a team of archaeologists to identify while still saving time overall on the task. Similarly, Zingman *et al.* (2016) have used CNNs to identify livestock enclosures in alpine areas and Caspari and Crespo (2019) have used CNNs to identify early Iron Age Saka burial mounds from freely available satellite imagery.

Some studies that have used object detection tools to identify archaeological features in remotely sensed data have noted that these methods are potentially less biased than human-based approaches. For example, a research team from Leiden University (Verschoof-van der Vaart and Lambers 2021) used an automated detection tool, called WODAN, to detect barrows and Celtic fields in the Netherlands. In this analysis, the authors found that automatic detection should not be viewed as a substitute for manual analysis but rather as a complementary method to help identify features that are not immediately apparent in the remotely sensed data. In doing so, automated detection tools can offset the potential bias of manual detection and vice versa.

While object detection algorithms are far from perfect, and some scholars still argue for the “brute force” method (Casana 2014; 2020), researchers have come a long way, and the future of these techniques is promising.

4.2 Object segmentation

The initial results of archaeological acquisitions can often be published with the raw data combined with manual and automated object identification to generate counts (Canuto *et al.* 2018; Evans 2016; Evans *et al.* 2013); however, archaeologists are left with the classic task of mapping these features by hand to gain additional information like size and volume. As such, archaeologists are increasingly lured by the potential of object segmentation to produce polygons of archaeological features that form the basic building blocks of archaeological maps (Kazimi *et al.* 2019).

Some archaeologists have begun combining masks with CNN models. For example, in a study of charcoal



Figure 5: Mapping overlaid over the lidar data of Angkor Wat. A more stylized mapping style would depict regular city blocks with even numbers and sizes of house mounds and ponds per city block.

hearths, Bonhage *et al.* (2021) created a Mask R-CNN model with an average precision of 87% and a recall of 83% of charcoal hearths. This high accuracy level means that most sites are identified correctly, and there are relatively few (13%) misidentified sites. However, the sites that are smaller tended to be more likely to be missed by the model. The authors were also able to create bounding boxes around the charcoal hearths, which tend to be larger than the actual sites. The size discrepancy makes using them as proxies for the areas of the sites problematic. Further, the bounding boxes are square, and while they can help give the viewer

an idea of the location and size of the feature, they are not ideal for determining attributes, like area. Guyot *et al.* (2021) have used CNN approaches with object segmentation and transfer learning to identify archaeological features in lidar data semi-automatically. Interestingly, their process successfully identified and drew polygons around archaeological features and is a promising new technique for archaeologists working with lidar data.

Sevara *et al.* (2016) have experimented with other semi-automated approaches for detecting and mapping archaeological features in remotely

sensed data. The authors compare pixel-based and object-oriented data classification methods on two case studies from Sweden and Austria. The authors found that object-based methods were more effective than pixel-based methods; however, the results could not replace human interpretation. Instead, they could greatly aid in the process by systematically identifying the majority of features and leaving the human interpreter to refine. The results of this type of analysis can be exported in vector-based formats, which are easily incorporated into geographic information system (GIS) software, where archaeologists can combine them with other GIS data.

The importance of the field of cartography to archaeology cannot be understated. The resulting maps from the archaeological lidar dataset allow our colleagues and lay individuals to understand the past landscapes and require less interpretation than looking at the lidar data itself. But the mapping itself is fraught with issues that could potentially be resolved through a more systematic and automated method because mapping the archaeological past, based on what remains on the present-day landscape, is highly subjective. For example, at Angkor Wat, it is evident that there was a centrally organized urban grid. Each city block consists of four or six house mounds and house ponds. We chose to map the archaeological record as it remains today (figure 5) but it may at times be helpful to use more stylized methods to depict how the urban forms most likely looked in the past.

Even when the choice is made to map what remains on the landscape, researchers are still faced with subjective decisions on every feature. When defining continuous data forms (elevation data) into binary and discrete polygons, a decision has to be made about where to literally draw the line between a house mound and a house pond. Even though the earth used to construct the mound also functions to contain the pond, whose water level varies with the season. With an automated method, rules could be set to consistently draw these lines between features based on relative changes in topography, slope, or other quantifiable metrics. This has been identified and referred to as *semantic consistency* by Davis and Lundin (2021), who suggest that a combination of manual and automated methods can help mitigate the impact of inconsistent bias. In such a way, the tools can help mitigate some of the human-introduced biases to archaeological mapping, as done with object detection algorithms (Verschoof-van der Vaart and Lambers 2021).

Finally, mapping remains, at its core, a combination of scientific and artistic endeavors as Leonardo da Vinci is remembered as both a scientist and an artist for his beautiful diagrams of, among other things, the human body. In much the same way, archaeologists must appreciate the artistic element of archaeological mapping in addition to the scientific. While automatically generated polygons sound unattractive, they could be designed to follow a set of rules, including smoothing parameters, that could result in a level of consistency and symmetry that is perceived as beautiful. Manual mapping requires a combination of elements and skills, including a deep knowledge of the site-specific archaeological record, the required drafting and geographic information systems analysis skills, and virtuoso. These are three skills that are rarely found in a single academic. Indeed, some have argued that creatively exploring remotely sensed imagery and the knowledge and nuance required to interpret the features should limit the work to these highly skilled individuals, and we should not attempt to automate the process (Casana 2020; 2014). As a result, the years of mapping are often undertaken by the project lead, usually one of few project members with the required skill set to complete the mapping work.

5 CONCLUSIONS AND STEPS FORWARD FOR KALC AND CALI

While much work has been done in terms of automated detection of archaeological features in remotely sensed data, there is much work yet to be done, both in terms of refining the models that are used for object detection but also to develop new models for object segmentation that will significantly reduce the onerous task of mapping archaeological features by hand. While advances have been made in other fields to use segmentation to identify different types of features, much work is still to be done before this process can be applied, unchecked, to the archaeological record.

A fine-grained analysis of the resulting archaeological information initially revealed through archaeological lidar datasets often requires maps to enable researchers to go beyond basic counts of archaeological features to include things like the area and volume of these features. This information is essential to answering a number of the questions that lie at the heart of some of the grand challenges for archaeology (Kintigh *et al.* 2014). For example, with these resulting maps, researchers for KALC and CALI have been able to calculate the total population

and population density over time of archaeological sites (Klassen *et al.* 2021), create models of hydraulic systems (Lustig *et al.* 2018), model water management systems over the long-term (Klassen *et al.* 2018), and strategically organize resources and determine targeted areas for archaeological investigations (Carter *et al.* 2018; 2019).

As our project looks toward the future and additional archaeological lidar datasets are acquired across the globe, we are optimistic that continued work and development in fields of automated segmentation will reduce the mapping demand placed on archaeologists. Such advances will save years spent mapping features by hand and allow researchers to move forward with research agendas that can potentially transform our understanding of the past.

REFERENCES

- Acker, R. 1998. "New Geographic Tests of the Hydraulic Thesis at Angkor." *South East Asia Research* 6: 5-47. DOI: 10.1177/0967828X9800600103.
- Gaughan, A.E., M.W. Binford, and J. Southworth. 2009. "Tourism, Forest Conversion, and Land Transformations in the Angkor Basin, Cambodia." *Applied Geography* 29 (2): 212-23. DOI: 10.1016/j.apgeog.2008.09.007.
- Bennett, R. 2014. "Airborne Laser Scanning for Archaeological Prospection." In *3D Recording and Modelling in Archaeology and Cultural Heritage: Theory and Best Practices*, edited by Fabio Remondino and Stefano Campana, 27-38. BAR International Series 2598.
- Berganzo-Besga, I., H.A. Orengo, F. Lumbreras, M. Carrero-Pazos, J. Fonte, and B. Vilas-Estévez. 2021. "Hybrid MSRM-Based Deep Learning and Multitemporal Sentinel 2-Based Machine Learning Algorithm Detects Near 10k Archaeological Tumuli in North-Western Iberia." *Remote Sensing* 13 (20): 4181. DOI: 10.3390/rs13204181.
- Bevan, A. 2015. "The Data Deluge." *Antiquity* 89 (348): 1473-84. DOI: 10.15184/aj.2015.102.
- Bonhage, A., M. Eltaher, T. Raab, M. Breuß, A. Raab, and A. Schneider. 2021. "A Modified Mask Region-based Convolutional Neural Network Approach for the Automated Detection of Archaeological Sites on High-resolution Light Detection and Ranging-derived Digital Elevation Models in the North German Lowland." *Archaeological Prospection* 28 (2): 177-86. DOI: 10.1002/arp.1806.
- Boulch, A., B. Le Saux, and N. Audebert. 2017. "Unstructured Point Cloud Semantic Labeling Using Deep Segmentation Networks," In *Proceedings of the Workshop on 3D Object Retrieval (3DOR '17)*. Eurographics Association, Goslar, DEU, 17-24. DOI: 10.2312/3dor.20171047
- Bourdonneau, E. 2003. "The Ancient Canal System of the Mekong Delta." In *Fishbones and Glittering Emblems: Southeast Asian Archaeology 2002*, edited by Anna Karlström and Anna Källén, 257-70. Stockholm: Museum of Far Eastern Antiquities.
- Bourdonneau, E. 2010. "Pour En Finir Avec La « cité Hydraulique » ?" *Bulletin de l'École Française d'Extrême-Orient* 97-98: 409-37.
- Brandsen, A., and M. Koole. 2022. "Labelling the Past: Data Set Creation and Multi-Label Classification of Dutch Archaeological Excavation Reports." *Language Resources and Evaluation* 56 (2): 543-72. DOI: 10.1007/s10579-021-09552-6.
- Brandsen, A., K. Lambers, S. Verberne, and M. Wansleeben. 2019. "User Requirement Solicitation for an Information Retrieval System Applied to Dutch Grey Literature in the Archaeology Domain." *Journal of Computer Applications in Archaeology* 2 (1): 21-30. DOI: 10.5334/jcaa.33.
- Bundzel, M., M. Jašćur, M. Kováč, T. Lieskovský, P. Sinčák, and T. Tkáčik. 2020. "Semantic Segmentation of Airborne LiDAR Data in Maya Archaeology." *Remote Sensing* 12 (22): 3685. DOI: 10.3390/rs12223685.
- Canuto, M.A., F. Estrada-Belli, T.G. Garrison, S.D. Houston, M.J. Acuña, M. Kováč, D. Marken, P. Nondédéo, L. Auld-Thomas, C. Castanet, D. Chatelain, C.R. Chiriboga, T. Drápela, T. Lieskovský, A. Tokovinine, A. Velasquez, J.C. Fernández-Díaz, and R. Shrestha. 2018. "Ancient Lowland Maya Complexity as Revealed by Airborne Laser Scanning of Northern Guatemala." *Science* 361 (6409). DOI: 10.1126/science.aau0137.
- Carter, A.K., P. Heng, M. Stark, R. Chhay, and D. Evans. 2018. "Urbanism and Residential Patterning in Angkor." *Journal of Field Archaeology* 43 (6): 492-506. DOI: 10.1080/00934690.2018.1503034.
- Carter, A.K., M.T. Stark, S. Quintus, Y. Zhuang, H. Wang, P. Heng, and R. Chhay. 2019. "Temple Occupation and the Tempo of Collapse at Angkor Wat, Cambodia." *Proceedings of the National Academy of Sciences* 116 (25): 12226-31. DOI: 10.1073/pnas.1821879116.
- Carter, A.K., S. Klassen, M.T. Stark, M. Polkinghorne, P. Heng, D. Evans, and R. Chhay. 2021. "The Evolution of Agro-Urbanism: A Case Study from Angkor, Cambodia." *Journal of Anthropological Archaeology* 63 (September): 101323. DOI: 10.1016/j.jaa.2021.101323.

- Casana, J. 2014. "Regional-Scale Archaeological Remote Sensing in the Age of Big Data: Automated Site Discovery vs. Brute Force Methods." *Advances in Archaeological Practice* 2 (3): 222-33. DOI:10.7183/2326-3768.2.3.222.
- Casana, J. 2020. "Global-Scale Archaeological Prospection Using CORONA Satellite Imagery: Automated, Crowd-Sourced, and Expert-Led Approaches." *Journal of Field Archaeology* 45 (sup1): S89-100. DOI:10.1080/00934690.2020.1713285.
- Caspari, G., and P. Crespo. 2019. "Convolutional Neural Networks for Archaeological Site Detection – Finding 'Princely' Tombs." *Journal of Archaeological Science* 110 (October): 104998. DOI:10.1016/j.jas.2019.104998.
- Castillo, C.C., A. Carter, E. Kingwell-Banham, Y. Zhuang, A. Weisskopf, R. Chhay, P. Heng, D.Q. Fuller, and M. Stark. 2020. "The Khmer Did Not Live by Rice Alone: Archaeobotanical Investigations at Angkor Wat and Ta Prohm." *Archaeological Research in Asia* 24 (December): 100213. DOI:10.1016/j.ara.2020.100213.
- Chase, A.F., D.Z. Chase, J.F. Weishampel, J.B. Drake, R.L. Shrestha, K.C. Slatton, J.J. Awe, and W.E. Carter. 2011. "Airborne LiDAR, Archaeology, and the Ancient Maya Landscape at Caracol, Belize." *Journal of Archaeological Science* 38 (2): 387-98. DOI:10.1016/j.jas.2010.09.018.
- Chase, A.F., and D.Z. Chase. 2017. "Detection of Maya Ruins by LiDAR: Applications, Case Study, and Issues." In *Sensing the Past: From Artifact to Historical Site*, edited by Nicola Masini and Francesco Soldovieri, 16:455-68. Cham, Switzerland: Springer. DOI:10.1007/978-3-319-50518-3_22.
- Chevance, J., D. Evans, N. Hofer, S. Sakhoeun, and R. Chhean. 2019. "Mahendraparvata: An Early Angkor-Period Capital Defined through Airborne Laser Scanning at Phnom Kulen." *Antiquity* 93 (371): 1303-21. DOI:10.15184/aqy.2019.133.
- Davis, D.S., and J. Lundin. 2021. "Locating Charcoal Production Sites in Sweden Using Lidar, Hydrological Algorithms, and Deep Learning." *Remote Sensing* 13 (18): 3680. DOI:10.3390/rs13183680.
- Demantké, J., C. Mallet, N. David, and B. Vallet. 2012. "Dimensionality Based Scale Selection In 3d Lidar Point Clouds." *ISPRS – International Archives of the Photogrammetry, Remote Sensing and Spatial Information Sciences XXXVIII-5/W12* (September): 97-102. DOI:10.5194/isprsarchives-XXXVIII-5-W12-97-2011.
- Evans, D. 2007. "Putting Angkor on the Map: A New Survey of a Khmer 'Hydraulic City' in Historical and Theoretical Context." PhD Thesis, Sydney: University of Sydney.
- Evans, D. 2013. "The Archaeological Landscape of Koh Ker, Northwest Cambodia." *Bulletin de l'École Française d'Extrême-Orient* 97-98: 91-150.
- Evans, D. 2016. "Airborne Laser Scanning as a Method for Exploring Long-Term Socio-Ecological Dynamics in Cambodia." *Journal of Archaeological Science* 74: 164-75. DOI:10.1016/j.jas.2016.05.009
- Evans, D., and R. Fletcher. 2015. "The Landscape of Angkor Wat Redefined." *Antiquity* 89 (348): 1402-19. DOI:10.15184/aqy.2015.157.
- Evans, D., R. Fletcher, C. Pottier, J.B. Chevance, D. Soutif, B.S. Tan, S. Im, D. Ea, T. Tin, S. Kim, C. Cromarty, S. De Greef, K. Hanus, P. Bâty, R. Kuszinger, I. Shimoda, and G. Boornazian. 2013. "Uncovering Archaeological Landscapes at Angkor Using Lidar." *Proc Natl Acad Sci U S A* 110 (31): 12595-600. DOI:10.1073/pnas.1306539110.
- Felzenszwalb, P.F., and D.P. Huttenlocher. 2004. "Efficient Graph-Based Image Segmentation." *International Journal of Computer Vision* 59 (2): 167-81. DOI:10.1023/B:VISI.0000022288.19776.77.
- Filin, S., and N. Pfeifer. 2005. "Neighborhood Systems for Airborne Laser Data." *Photogrammetric Engineering & Remote Sensing* 71 (6): 743-55. DOI:10.14358/PERS.71.6.743.
- Fiorucci, M., W.B. Verschoof-van der Vaart, P. Soleni, B. Le Saux, and A. Traviglia. 2022. "Deep Learning for Archaeological Object Detection on LiDAR: New Evaluation Measures and Insights." *Remote Sensing* 14 (7): 1694. DOI:10.3390/rs14071694.
- Fletcher, R., and C. Pottier. 2002. "The Gossamer City: A New Inquiry." *Museum International* 54 (1-2): 23-27. DOI:10.1111/1468-0033.00360.
- Fletcher, R., C. Pottier, D. Evans, and M. Kummu. 2008. "The Development of the Water Management System of Angkor: A Provisional Model." *Bulletin of the Indo-Pacific Prehistory Association* 28: 347-54.
- Fletcher, R., and K. White. 2018. "Tropical Environments and Trajectories to Low-Density Settlement Forms." In *Exploring Frameworks for Tropical Forest Conservation: Integrating Natural and Cultural Diversity For Sustainability: A Global Perspective*. UNESCO.
- Fukui, H. 1999. "Groslier's Hydraulic Society Theory of Angkor in the Eyes of an Agroecologist [農業生態から見たグロリエのアンコール水利社会説批判]." *Southeast Asian Studies* 36 (4): 546-54.
- Gallwey, J., M. Eyre, M. Tonkins, and J. Coggan. 2019. "Bringing Lunar LiDAR Back Down to Earth:

- Mapping Our Industrial Heritage through Deep Transfer Learning.” *Remote Sensing* 11 (17): 1994. DOI:10.3390/rs11171994.
- Gaucher, Jacques. 2002. “The ‘city’ of Angkor. What Is It?” *Museum International* 54 (1-2): 28-36. DOI:10.1111/1468-0033.00361.
- Gaucher, J. 2003a. “New Archaeological Data on the Urban Space of the Capital City of Angkor Thom.” In *Fishbones and Glittering Emblems: Southeast Asian Archaeology 2002*, edited by Anna Karlström and Anna Källén, 233-42. Stockholm: Museum of Far Eastern Antiquities.
- Gaucher, J. 2003b. “Premiers Aperçus Sur Des Éléments De Planification Urbaine À Angkor Thom.” *Udaya, Journal of Khmer Studies* 4: 41-52.
- Gaucher, J. 2004. “Angkor Thom, Une Utopie Réalisée? Structuration de l’espace et Modèle Indien d’urbanisme Dans Le Cambodge Ancien.” *Arts Asiatiques* 59: 58-86.
- Gaucher, J. 2017. “L’enceinte d’Angkor Thom : Archéologie d’une Forme et Chronologie d’une Ville.” In *Deux Décennies de Coopération Archéologique Franco-Cambodgienne à Angkor*, 27-41. Paris: Académie des Inscriptions et Belles-Lettres.
- Girshick, R., J. Donahue, T. Darrell, and J. Malik. 2014. “Rich Feature Hierarchies for Accurate Object Detection and Semantic Segmentation.” *ArXiv:1311.2524* [Cs], October. <http://arxiv.org/abs/1311.2524>.
- Guyot, A., M. Lennon, T. Lorho, and L. Hubert-Moy. 2021. “Combined Detection and Segmentation of Archeological Structures from LiDAR Data Using a Deep Learning Approach.” *Journal of Computer Applications in Archaeology* 4 (1): 1. DOI:10.5334/jcaa.64.
- Hall, T., D. Penny, and R. Hamilton. 2018. “Re-Evaluating the Occupation History of Koh Ker, Cambodia, during the Angkor Period: A Palaeo-Ecological Approach.” *PLOS ONE* 13 (10): e0203962. DOI:10.1371/journal.pone.0203962.
- Hanus, K., and D. Evans. 2015. “Imaging the Waters of Angkor: A Method for Semi-Automated Pond Extraction from LiDAR Data.” *Archaeological Prospection* 23 (2): 87-94. DOI:10.1002/arp.1530.
- Hawken, S. 2011. “Metropolis of Ricefields: A Topographical Classification of a Dispersed Urban Complex.” The University of Sydney.
- He, K., G. Gkioxari, P. Dollár, and R. Girshick. 2018. “Mask R-CNN.” *ArXiv:1703.06870* [Cs], Accessed January, 2023. <http://arxiv.org/abs/1703.06870>.
- Hendrickson, M. 2010. “Historic Routes to Angkor: Development of the Khmer Road System (Ninth to Thirteenth Centuries AD) in Mainland Southeast Asia.” *Antiquity* 84 (324). DOI:10.1017/S0003598X00066722.
- Heng, P., A.K. Carter, C. Rachna, and M. Stark. 2015. “Ta Prohm June-July 2014.” *Greater Angkor Project 2011-2015: Preliminary Reports Series*.
- Jacob, J.M. 1978. “The Ecology of Angkor: Evidence from the Khmer Inscriptions.” In *Nature and Man in South East Asia*, edited by P. A. Stott, 109-27. London: School of African and Oriental Studies, University of London.
- Kazimi, B., F. Thiemann, and M. Sester. 2019. “Semantic Segmentation of Manmade Landscape Structures in Digital Terrain Models.” *ISPRS Annals of the Photogrammetry, Remote Sensing and Spatial Information Sciences* IV-2/W7 (September): 87-94. DOI:10.5194/isprs-annals-IV-2-W7-87-2019.
- Kintigh, K.W., J.H. Altschul, M.C. Beaudry, R.D. Drennan, A.P. Kinzig, T.A. Kohler, W.F. Limp, H.D. G. Maschner, W.K. Michener, T.R. Pauketat, P. Peregrine, J.A. Sabloff, T.J. Wilkinson, H.T. Wright and M.A. Zeder. 2014. “Grand Challenges for Archaeology.” *American Antiquity* 79 (1): 5-24. DOI:10.7183/0002-7316.79.1.5.
- Klassen, S., T. Attorre, P. Phin, S. Phin, and A. Loyless. 2022. “Updates from the Koh Ker Archaeological Project.” Paper presented at the Society for American Archaeology 87th Annual meeting March 30-April 3, 2022 Chicago, Illinois.
- Klassen, S., A.K. Carter, D.H. Evans, S. Ortman, M.T. Stark, A.A. Loyless, M. Polkinghorne, P. Heng, M. Hill, P. Wijker, J. Niles-Weed, G.P. Marriner, C. Pottier, and R.J. Fletcher. 2021. “Diachronic Modeling of the Population within the Medieval Greater Angkor Region Settlement Complex.” *Science Advances* 7 (19): eabf8441. DOI:10.1126/sciadv.abf8441.
- Klassen, S., and D. Evans. 2020. “Top-down and Bottom-up Water Management: A Diachronic Model of Changing Water Management Strategies at Angkor, Cambodia.” *Journal of Anthropological Archaeology* 58 (June): 101166. DOI:10.1016/j.jaa.2020.101166.
- Klassen, S., J. Weed, and D. Evans. 2018. “Semi-Supervised Machine Learning Approaches for Predicting the Chronology of Archaeological Sites: A Case Study of Temples from Medieval Angkor, Cambodia.” *PLOS ONE* 13 (11): e0205649. DOI:10.1371/journal.pone.0205649.

- Kummu, M. 2009. "Water Management in Angkor: Human Impacts on Hydrology and Sediment Transportation." *Journal of Environmental Management* 90: 1413-21. DOI: 10.1016/j.jenvman.2008.08.007.
- Landrieu, L., H. Ragué, B. Vallet, C. Mallet, and M. Weinmann. 2017. "A Structured Regularization Framework for Spatially Smoothing Semantic Labelings of 3D Point Clouds." *ISPRS Journal of Photogrammetry and Remote Sensing* 132 (October): 102-18. DOI: 10.1016/j.isprsjprs.2017.08.010.
- Lasaponara, R., and N. Masini. 2011. "Satellite Remote Sensing in Archaeology: Past, Present and Future Perspectives." *Journal of Archaeological Science* 38 (9): 1995-2002. DOI: 10.1016/j.jas.2011.02.002.
- LeCun, Y., Y. Bengio, and G. Hinton. 2015. "Deep Learning." *Nature* 521 (7553): 436-44. DOI: 10.1038/nature14539.
- Lustig, T., S. Klassen, D. Evans, R. French, and I. Moffat. 2018. "Evidence for the Breakdown of an Angkorian Hydraulic System, and Its Historical Implications for Understanding the Khmer Empire." *Journal of Archaeological Science: Reports* 17 (February): 195-211. DOI: 10.1016/j.jasrep.2017.11.014.
- Masini, N., R. Coluzzi, and R. Lasaponara. 2011. "On the Airborne Lidar Contribution in Archaeology: From Site Identification to Landscape Investigation." *Laser Scanning, Theory and Applications*, 263-90.
- Mizoguchi, A., and T. Nakagawa. 2011. *Koh Ker and Beng Mealea: Two Large Monuments at the Eastern Portion of the Khmer Empire*. Japan: Grants-in-Aid for Scientific Research (A): Overseas Project Japan Society for the Promotion of Science 2007 to 2010.
- Moffat, I., S. Klassen, T. Attorre, D. Evans, T. Lustig, and L. Kong. 2020. "Using Ground Penetrating Radar to Understand the Failure of the Koh Ker Reservoir, Northern Cambodia." *Geoarchaeology* 35 (1): 63-71. DOI: 10.1002/gea.21757.
- Opitz, R.S. 2013. "An Overview of Airborne and Terrestrial Laser Scanning in Archaeology." In *Interpreting Archaeological Topography: 3D Data, Visualisation and Observation*, edited by R.S. Opitz and D.C. Cowley, 13-31. Oxford: Oxbow Books.
- Pottier, C. 1999. "Carte Archéologique de La Région d'Angkor. Zone Sud." PhD Thesis, Université Paris III – Sorbonne Nouvelle.
- Pottier, C. 2000. "Some Evidence of an Inter-Relationship between Hydraulic Features and Rice Field Patterns at Angkor during Ancient Times." *Journal of Sophia Asian Studies* 18: 99-120.
- Qi, C.R., H. Su, K. Mo, and L.J. Guibas. 2017. "PointNet: Deep Learning on Point Sets for 3D Classification and Segmentation." *ArXiv:1612.00593* [Cs], April. <http://arxiv.org/abs/1612.00593>.
- Qi, C.R., H. Su, M. NieBner, A. Dai, M. Yan, and L.J. Guibas. 2016. "Volumetric and Multi-View CNNs for Object Classification on 3D Data." In *2016 IEEE Conference on Computer Vision and Pattern Recognition (CVPR)*, 5648-56. Las Vegas, NV, USA: IEEE. DOI: 10.1109/CVPR.2016.609.
- Ren, S., K. He, R. Girshick, and J. Sun. 2016. "Faster R-CNN: Towards Real-Time Object Detection with Region Proposal Networks." *ArXiv:1506.01497* [Cs], January. <http://arxiv.org/abs/1506.01497>.
- Renner, Z. 2011. *Koh Ker Project: Annual Report 2011*. Budapest: Magyar Indokina Társaság Kft.
- Riegler, G, A.O. Ulusoy, and A. Geiger. 2017. "OctNet: Learning Deep 3D Representations at High Resolutions." *ArXiv:1611.05009* [Cs], April. <http://arxiv.org/abs/1611.05009>.
- Sedov, L.A. 1963. "On the Problem of the Economic System in Angkor Cambodia in the IX XII Centuries." In *Narody Asii I Afriki, Istorija, Ekonomika, Kul'tura*, translated by Antonia Glasse, 6:73-81. Akademiya Nauk SSR.
- Sevara, C., M. Pregesbauer, M. Doneus, G. Verhoeven, and I. Trinks. 2016. "Pixel versus Object – A Comparison of Strategies for the Semi-Automated Mapping of Archaeological Features Using Airborne Laser Scanning Data." *Journal of Archaeological Science: Reports* 5 (February): 485-98. DOI: 10.1016/j.jasrep.2015.12.023.
- Somrak, M., S. Džeroski, and Ž. Kokalj. 2020. "Learning to Classify Structures in ALS-Derived Visualizations of Ancient Maya Settlements with CNN." *Remote Sensing* 12 (14): 2215. DOI: 10.3390/rs12142215.
- Soroush, M., A. Mehrtash, E. Khazraee, and J.A. Ur. 2020. "Deep Learning in Archaeological Remote Sensing: Automated Qanat Detection in the Kurdistan Region of Iraq." *Remote Sensing* 12 (3): 500. DOI: 10.3390/rs12030500.
- Stark, M. 2004. "Pre-Angkorian and Angkorian Cambodia." In *Southeast Asia: From Prehistory to History*, edited by P. Bellwood and I.C. Glover, 89-119. New York: Routledge Curzon Press.
- Stark, M., D. Evans, C. Rachna, H. Piphal, and A. Carter. 2015. "Residential Patterning at Angkor Wat." *Antiquity* 89 (348): 1439-55. DOI: 10.15184/aqy.2015.159.
- Stott, P. 1992. "Angkor: Shifting the Hydraulic Paradigm." In *The Gift of Water: Water*

- Management, Cosmology and the State in South East Asia*, edited by J. Rigg, 47-58. London: School of Oriental and African Studies.
- Thomas, H., C.R. Qi, J. Deschaud, B. Marcotegui, F. Goulette, and L.J. Guibas. 2019. "KPConv: Flexible and Deformable Convolution for Point Clouds." *ArXiv:1904.08889* [Cs], August. <http://arxiv.org/abs/1904.08889>.
- Traviglia, A., D. Cowley, and K. Lambers. 2016. "Finding Common Ground: Human and Computer Vision in Archaeological Prospection." *AARGnews* 53 (September): 11-24.
- Trier, Ø.D., D.C. Cowley, and A. Ueland Waldeland. 2019. "Using Deep Neural Networks on Airborne Laser Scanning Data: Results from a Case Study of Semi-automatic Mapping of Archaeological Topography on Arran, Scotland." *Archaeological Prospection* 26 (2): 165-75. DOI:10.1002/arp.1731.
- Trier, Ø.D., J.H. Reksten, and K. Løseth. 2021. "Automated Mapping of Cultural Heritage in Norway from Airborne Lidar Data Using Faster R-CNN." *International Journal of Applied Earth Observation and Geoinformation* 95 (March): 102241. DOI:10.1016/j.jag.2020.102241.
- Uijlings, J.R.R., K.E.A. van de Sande, T. Gevers, and A.W.M. Smeulders. 2013. "Selective Search for Object Recognition." *International Journal of Computer Vision* 104 (2): 154-71. DOI:10.1007/s11263-013-0620-5.
- Verschoof-van der Vaart, W.B., and K. Lambers. 2019. "Learning to Look at LiDAR: The Use of R-CNN in the Automated Detection of Archaeological Objects in LiDAR Data from the Netherlands." *Journal of Computer Applications in Archaeology* 2 (1): 31-40. DOI:10.5334/jcaa.32.
- Verschoof-van der Vaart, W.B., and K. Lambers. 2021. "Applying Automated Object Detection in Archaeological Practice: A Case Study from the Southern Netherlands." *Archaeological Prospection*, June, arp.1833. DOI:10.1002/arp.1833.
- Weinmann, M., B. Jutzi, S. Hinz, and C. Mallet. 2015. "Semantic Point Cloud Interpretation Based on Optimal Neighborhoods, Relevant Features and Efficient Classifiers." *ISPRS Journal of Photogrammetry and Remote Sensing* 105 (July): 286-304. DOI:10.1016/j.isprsjprs.2015.01.016.
- Zingman, I., D. Saupe, O.A.B. Penatti, and K. Lambers. 2016. "Detection of Fragmented Rectangular Enclosures in Very High Resolution Remote Sensing Images." *IEEE Transactions on Geoscience and Remote Sensing* 54 (8): 4580-93. DOI:10.1109/TGRS.2016.2545919.

Bibliometric Analysis of Agent-Based Simulation in Archaeology: People, Topics, and Future Prospects

Iza Romanowska and Fulco Scherjon

1 INTRODUCTION

Simulation was introduced into archaeological research on the premise of recreating long-gone worlds of past peoples in vivid detail for all to see. It was hailed as the long-sought time-travel machine that will allow researchers to fully understand the social dynamics of ancient groups, unpick the complex interaction between different actors and their environments and even exercise experiments in "alternative histories". It has been repeatedly pointed out that modelling is a necessary tool in the archaeological toolbox due to the very nature of archaeological data (Lake 2014). Where other scientists can rely on direct experiments or observation enabling them to collect systematic and reliable data, the archaeological record consists of only fragments of the original social systems tainted by a myriad of post-depositional biases and usually represents just a proxy of the past processes archaeologists are interested in. Relying on data alone is simply not enough. Many computational archaeologists welcomed simulation techniques as a potential remedy for the gaps and biases in the data and a way to finally crack the complex and dynamic character of the social and socio-natural phenomena studied (Rogers and Cegielski, 2017; Romanowska *et al.* 2021).

Despite this clear fit for archaeology, simulation, including its most common type: agent-based modelling (ABM), has been advancing in archaeology at a much slower pace than would be expected given its transformative power experienced by other disciplines (Gilbert and Troitzsch, 2011; Poisot *et al.* 2019). While it has been present in projects, research teams, papers and conference sessions the early expectations that it will follow the trajectories of GIS, 3D modelling or remote sensing shooting in popularity within a few years have not come to pass. While it would be easy to speculate on the multiple reasons behind this trend and how it may be mirroring the underlying structure of the discipline, we are more interested in characterising the historical trends in archaeological simulation, the people involved in it and the topics they work on. Understanding the past and describing the present is likely to give us clues as to what the future holds for archaeological simulation.

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1.1 Simulation, agent-based modelling and formal theory building

Simulation is a scientific technique in which a real-world system is represented in a simplified way and can be experimented on. Simulation techniques enable the investigation of dynamic processes and causal relationships that may not be immediately apparent from the known characteristics of the studied systems or from the data these systems generate. Virtually all disciplines of science use simulation, although often in different contexts and different functions (Hartmann 1996).

Historically the simulation tool of choice for archaeology has been agent-based modelling (ABM) (Davies and Romanowska 2018; Rogers and Cegielski 2017). It focuses on individual software units – agents who act and interact autonomously depending on their individual circumstances (Gilbert and Troitzsch 2011; Premo 2010; Romanowska 2015). The alternative technique, that is, equation-based modelling (Premo 2006), including numerical simulation/dynamic mathematical models such as, system dynamics, discrete events, deterministic or stochastic, etc., is by far the most ubiquitous simulation technique across Science, Technology, Engineering and Mathematics (STEM) subjects (Dubois 2018; Leonelli 2021; Poist *et al.* 2019; Sterman 2000; Székely and Burrage 2014). Nevertheless, ABM has carved for itself a niche through the wider theoretical framework of complexity science – a paradigm concerned with non-linear complex systems where interactions between individuals lead to unexpected global patterns (De Domenico and Sayama 2019; Romanowska *et al.* 2021). It speaks well to researchers who see subjects rather than objects in the systems they study – biologists (especially ecologists), social scientists or archaeologists. It stresses the importance of intentionality and individual agency, information transmission through learning, innovation or adaptation and heterogeneity in the population expressed as the individuality and uniqueness of each agent (Crooks and Heppenstall 2012; Hamill and Gibert 2016; Railsback and Grimm 2011; Romanowska *et al.* 2021).

At the same time, ABM combines the rigour of formal mathematical description with considerable ease of use (Crabtree *et al.* 2019; Davies *et al.* 2019; Romanowska *et al.* 2019). It involves entities (agents, environment, links, objects) expressed in terms familiar to anyone. Where an equation may use a Greek letter to signify a change in the rate of growth of a population, ABM is likely to operate in male and female agents who, upon fulfilling some criteria (*e.g.*, age), create a new “baby” agent and bestow it with certain characteristics. The latter approach is inherently more intuitively understandable, which is an important consideration in disciplines where the mathematical notation is not commonly used.

ABM is not only dealing with familiar entities but also comes with one of the most user-friendly programming frameworks: NetLogo (Wilensky 1999). Thanks to its single functional objective: building and running ABM simulations as well as its educational origins (its precursor was Logo – a programming language

designed for education purposes) it is easy to read and easy to write. The low entry point, combined with high capabilities make NetLogo an ideal tool for disciplines with a shorter history of computational research, such as archaeology. In fact, a recent survey (Davies and Romanowska 2018) found that almost 80% of modellers in archaeology (among survey respondents) actively use NetLogo in their research, followed by classic programming languages (R and Python at 28% and 20% respectively) and other ABM platforms (Repast, Mason, AnyLogic, Swarm, Matlab – all but Repast with 11% used by fewer than 10% of modellers).

In this paper, we focus on archaeological ABM and the community of archaeological ABM modellers as an easy to identify set of practitioners. Compared to researchers that applied other simulation techniques to archaeology (mostly equation-based) it comprises predominantly “home-grown” scholars rather than experts from other fields jumping in to do a side project (approx. 75% of survey respondents declared their first degree was in humanities, mostly archaeology or anthropology: Davies and Romanowska 2018; this is also our general impression). There is also a higher level of coherence of this community, with common venues for publishing and presenting archaeological ABM research and closer collaboration with the domain specialists (often because the modeller themselves is primarily a domain specialist). We, being practitioners ourselves, also believe that ABM is likely to remain the simulation technique of choice for archaeologists and it is its future that we should invest in.

2 MATERIALS AND METHODS: MEASURING THE BIBLIOMETRICS OF ARCHAEOLOGICAL MODELLING

Comprehensive accounts of the history of archaeological simulation based on close reading exist (*e.g.*, Lake 2008; 2014) and provide a compelling narrative regarding the development of the community in the wider disciplinary context. Here we turn to a more distant view through bibliometric analysis to take a wider view and explore large-scale patterns, lines of influence and the structure of the subdiscipline of archaeological ABM. In contrast to common methods of review in archaeology (*e.g.*, systematic reviews), bibliometric analysis is (typically) not concerned with examining the content of papers to summarise what is known on a particular issue, but rather with mapping out the scientific field by analysing its literature to uncover patterns, trends and relationships. Our aim in doing this is to explore which disciplines and concepts dominate the field,

with particular attention paid to those concepts which relate to ABM and simulation compared to archaeology in general. This should enable a deeper understanding of where the subdiscipline of archaeological ABM modelling is now and how it got here, which in turn provides a solid basis to define and explore the future promises and to characterise the current impasse.

2.1 Data

The corpus of publications used in the analysis has been compiled from the following sources:

- Scopus and Web of Science (WoS) – the two largest citation databases that contain abstracts of peer-reviewed papers in scientific journals, books and also conference proceedings. While both of them provide high-quality datasets their coverage of SSH (Social Sciences and Humanities) publications is notoriously poor (Melchiorson 2019). This presents a significant limitation to any study of archaeological output since Scopus and WoS indexing exclude some of the major archaeological journals, monographs, edited volumes, conference proceedings, etc.
- Google Scholar – a web search engine that crawls the web and indexes academic publications across all disciplines and formats. This data is not curated like in Scopus or WoS and can therefore contain duplicates, files mistakenly identified as publications or misattributed papers.
- ResearchGate, Academia – academic platforms used by researchers to display and promote their work. Here researchers themselves list and upload their publications. Often this is the only place where one can find papers published prior to the 1990s or those published in edited volumes and similar venues that have not been indexed. The major limitation is that not all scientists have a profile or share all of their publications.

To compile the most comprehensive corpus we have used all of the sources above in a way that maximises their utility and minimises deficiencies. In the first step, Scopus and WoS were searched with the following strategy:

- Define a search term: (archaeology OR archeology) (agent based);
- Select those papers where the Topic, Title, Author, Publication Titles, Year Published, Affiliation, and/or Publisher include the search term.

We manually cleaned the resulting dataset by excluding duplicates, book reviews, papers mentioning ABM but not being explicitly about the topic (*e.g.*, as a possible future direction), general overviews (*e.g.*, of trends in computational archaeology) and publications that were mistakenly attributed to archaeology (*e.g.*, those that referred to anthropological studies). The goal was to identify all archaeological research that used ABM and studies discussing its methodology within archaeology. The search term automatically excluded any publications in languages other than English, these were identified in the next step of the manual search. In general, while the authors were able to track publications in almost all European languages, potential archaeological ABM papers in other languages would not be identified.

Second, we used this dataset as well as Google Scholar, ResearchGate and several overview publications to identify names of researchers who undertook ABM work in the past. We then identified publications where ABM was used through their Google Scholar, ResearchGate, Academia and institutional websites profiles. In total, this comprehensive search resulted in 374 publications in the corpus. This was accompanied by a search (archaeology + agent-based) in ScienceDirect (Elsevier), SpringerLink (Springer) and CambridgeCore (Cambridge University Press), the CAA proceedings as well as several multidisciplinary journals: Nature, Science, PNAS, and PLoS One. Every time a new researcher was identified, a search through their publication record was undertaken to identify all publications involving ABM. By combining automatic selection with a manual search we were able to avoid some of the pitfalls of automatic corpus extraction from databases or noisy data. However, this approach is not without its limitations. Papers written by researchers who published little and were not cited by others might have been missed. Also, we used our professional judgement to decide whether a given publication should be considered “archaeology” (as opposed to anthropology, history, social science or computer science). As a rule of thumb, we deemed a paper “archaeological” if it aimed to answer an archaeological research question. Thus publications describing methodologies or abstract models applicable to different social sciences were excluded even if they were of interest to archaeological modellers. Despite these limitations, we believe this is the most comprehensive dataset of papers on archaeological ABMs that can be practically collected. The dataset is shared as an open Zotero library (<https://www.zotero.org/groups/4475617/archabm/library>) as a living document that can be updated.

2.2 Methods

In bibliometric analysis, the most commonly studied types of relations are citation relations (direct citation, co-citation and bibliographic coupling), keyword co-occurrence relations and co-authorship relations. We first recorded the number of publications per year. We then looked at the related terms and terminology through time. Finally, we focussed on the researchers themselves.

The datasets we approached contain data for varying time windows. Where possible we obtained data from as early as 1975, while the bulk is from the years 1999-2020. We analysed the following data:

- A count of the number of papers per year
- Clusters of papers linked by the similarity of content (based on abstracts)
- Relation between researchers
- The journals that published the papers

First, we simply counted the number of archaeological ABM papers per year for the last three decades and we compared it to the total number of publications in archaeology in general and those in another subfield (Palaeolithic Archaeology) to ensure that we balance out the general growth of archaeology and the steadily growing number of publications in the discipline. The subdiscipline of Palaeolithic Archaeology was chosen as it is a long-recognised branch of archaeology with well-defined boundaries, communities and research infrastructure (such as dedicated degrees and departments). Being a “classical” part of archaeology and very steady in its development over the last few decades, we deemed it representative enough for the whole discipline. Both authors have done research in Palaeolithic archaeology and, therefore, know the topics and the community well. This was done with the WoS query result data since detailed semi-manual data collection of all archaeological publications was not feasible. We followed the assumption that while the WoS data does not include many existing publications, the percentage missing will not differ significantly between the archaeological ABM dataset and the general archaeology dataset.

Second, text data was visualised and analysed with a tool designed to investigate bibliometric networks – VOSviewer (<http://www.vosviewer.com>) resulting in a series of cluster graphs (figure 4 – figure 8) that visualize the topics of publications, the authors and their interactions in archaeological ABM modelling. To allow the creation of such graphs, natural language processing

algorithms identify key elements like names of authors or unified noun phrases describing topics of the papers (van Eck and Waltman 2011). The terms are counted over all papers and their relevance and relatedness is calculated. Relatedness counts how often terms occur close together. Relevance is somewhat more complex with a high relevance score indicating that those terms are often associated with the same specific words, while more general words are less relevant and are more randomly associated with other words. More related terms are visualised closer together. The strongest relations are represented with lines between terms. Only the most relevant terms are shown in the network visualisation module of VOSviewer (for details on the algorithms used, see: Van Eck *et al.* 2009).

Finally, we undertook a co-citation analysis of the selected archaeological literature. This method is based on the assumption that documents cited together share some kind of intellectual affinity that reveals lines of influence visualised as a network map. As De Bellis (2009) notes, ‘co-citation analysis may be used to trace the map of relationships among documents/ key concepts, to outline and graphically visualise the structure of a research field, its connections with other fields, and its articulation into subfields and new research fronts’ (p. xxvi). Co-citation occurs when two publications are cited from a third paper (Marshakova 1973). The more publications that co-cite these two publications, the stronger the co-citation link between these two publications. Co-citation analysis can be used to study relations between papers, but also between researchers (White and Griffith 1981) and between journals (McCain 1991). When two papers both refer to a third paper they are said to be bibliographically coupled, *i.e.*, the opposite of co-citation. The more references they have in common, the stronger this coupling (Van Eck and Waltman 2014). To construct a co-citation network, a so-called match key is created for each cited reference to uniquely and uniformly identify a paper (https://www.vosviewer.com/documentation/Manual_VOSviewer_1.6.8.pdf). The constructed networks are weighted, where edges also indicate the strength of the relation between items (Van Eck and Waltman 2014).

3 RESULTS

The three types of analysis enable us to discuss: 1. the changing popularity of ABM in archaeology, the timing of the first applications and the rate of growth; 2. The main topics and research interest and how they relate to each other, and 3. The interactions and relationships

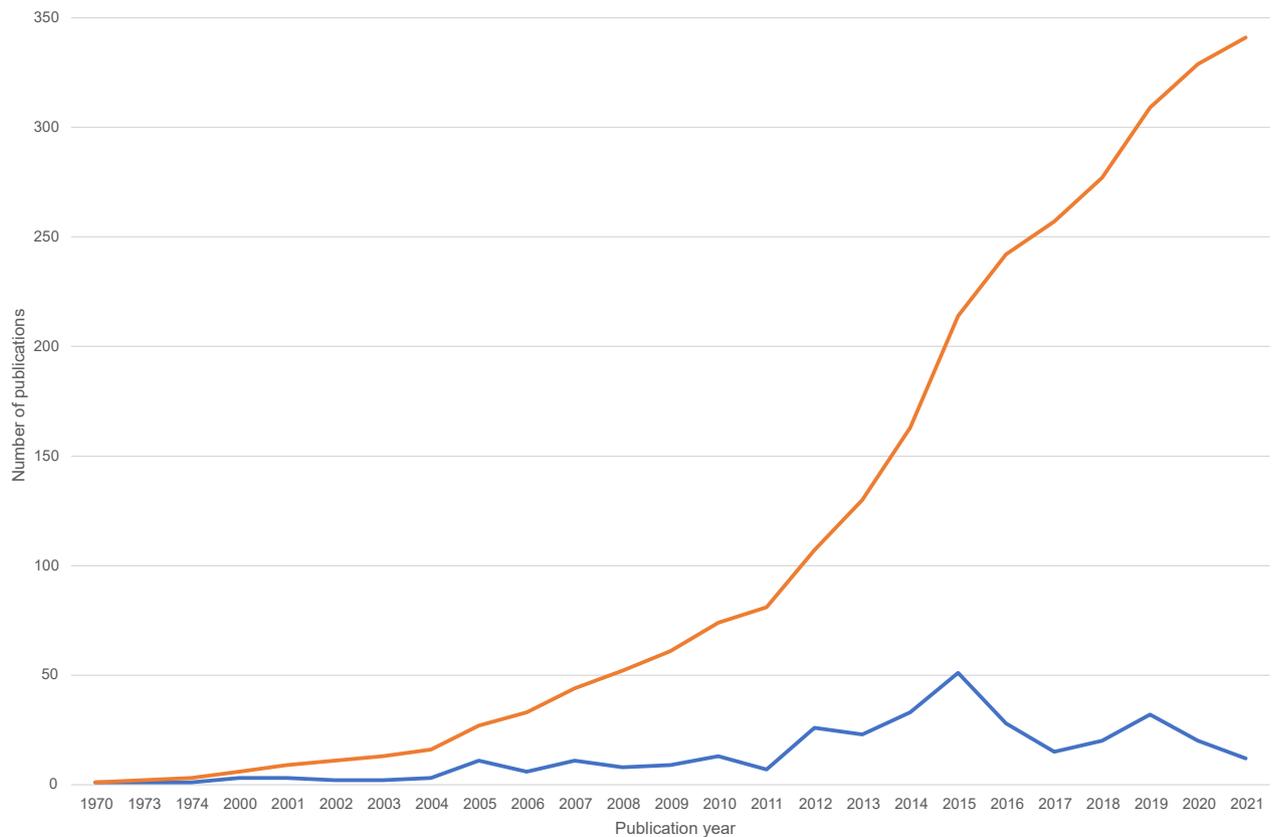


Figure 1: Number of ABM publications per year (blue) and cumulative (orange).

between the archaeological ABM modellers and the type of research landscape they find themselves in.

3.1 The changing popularity of ABM in archaeology

The graph of the number of ABM publications in archaeology per year (figure 1) shows a steady increase with a peak around the years 2014-2016 after which the numbers start to stabilise. While it is common to see a drop in the number of publications in the final couple of years due to delays in indexing, here the data collection was manual and while it is possible that some papers published in 2021 and maybe in 2020 were missed the downward trend seems to begin much earlier with a notable trough in 2017.

The cumulative graph confirms Lake's (2014) assessment that the true growth of archaeological ABM started at the turn of the millennium. The following decades show consistent yet slow growth. However, this growth needs to be regarded in a larger context of archaeological research outputs. D. Rocks-Mcqueen noted (personal communication through a conference presentation at CAA 2017-Atlanta)

that the size of different types of academic outputs (number of publications, number of practitioners, etc) in archaeological research has been on a growth trajectory over the last decades. To test this assertion we used the WoS corpus and compared three fields in terms of the number of publications: archaeology (search term: archaeology or archeology), palaeolithic archaeology (search term: (archaeology OR archeology) (paleolithic OR palaeolithic)) and archaeological ABM (search term: (archaeology OR archeology) (agent based))¹. This enables us

- 1 The following search criteria were included:
 - Select papers where the Topic, Title, Author, Publication Titles, Year Published, Affiliation, and/or Publisher include the search term;
 - We excluded book reviews, and results from the year 2021 (year was incomplete at the moment of searching);
 - Results were retrieved from the Web of Science Core Collection.

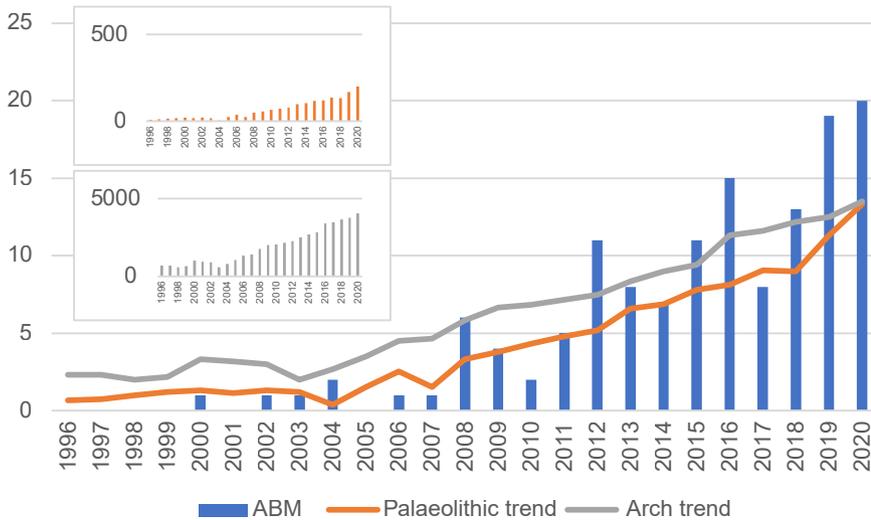


Figure 2: Number of archaeological publications per year compared to trend lines for Archaeology (grey line) and an established subfield of archaeology: Palaeolithic Archaeology (orange line). The trend lines were scaled to the ABM numbers by dividing the “Palaeolithic” trend by a factor of 15 and the “Archaeology” trend by 300.

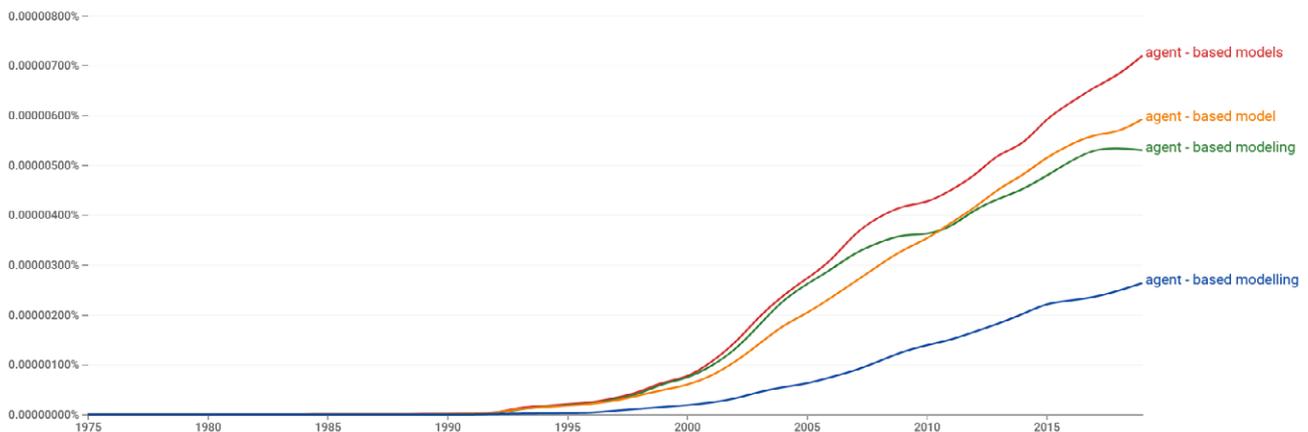


Figure 3: Google Ngram viewer results for agent-based modelling.

to contrast the general discipline (archaeology, 47,260 publications) and a well-established subfield (palaeolithic studies, 1,623 publications) against archaeological ABM (136 publications). There was a minimal overlap (five publications) between these two datasets.

The results (figure 2) show that both the field of archaeology and the subfield of Palaeolithic archaeology have gone through a substantial increase in their research output. In simple terms, there are more archaeologists and they publish more. Thus the trends for ABM publications in archaeology need to be calibrated against the general pattern of “inflation” of academic research.

In addition, we looked at the popularity of agent-based modelling across all scientific domains using

Wikidata query service and Google Ngram (Michel *et al.* 2011). Both aggregate large corpora of data (Wikidata and Google Books respectively) and can be useful in delineating general trends in the popularity of a given term (figure 3). Both graphs show a qualitatively similar pattern of a rapid rise of ABM in the first decade of the 21st century that continued until at least the middle of the second decade (the indexing usually accrues a delay of a few years making the last records unreliable).

The results show that archaeological ABM has increased as a proportion of all research output in archaeology and it has kept pace with other subdisciplines but probably not outpacing them in any substantial way. This can be compared with the meteoric rise of other techniques, for example, remote sensing which saw an eight-fold increase in the number

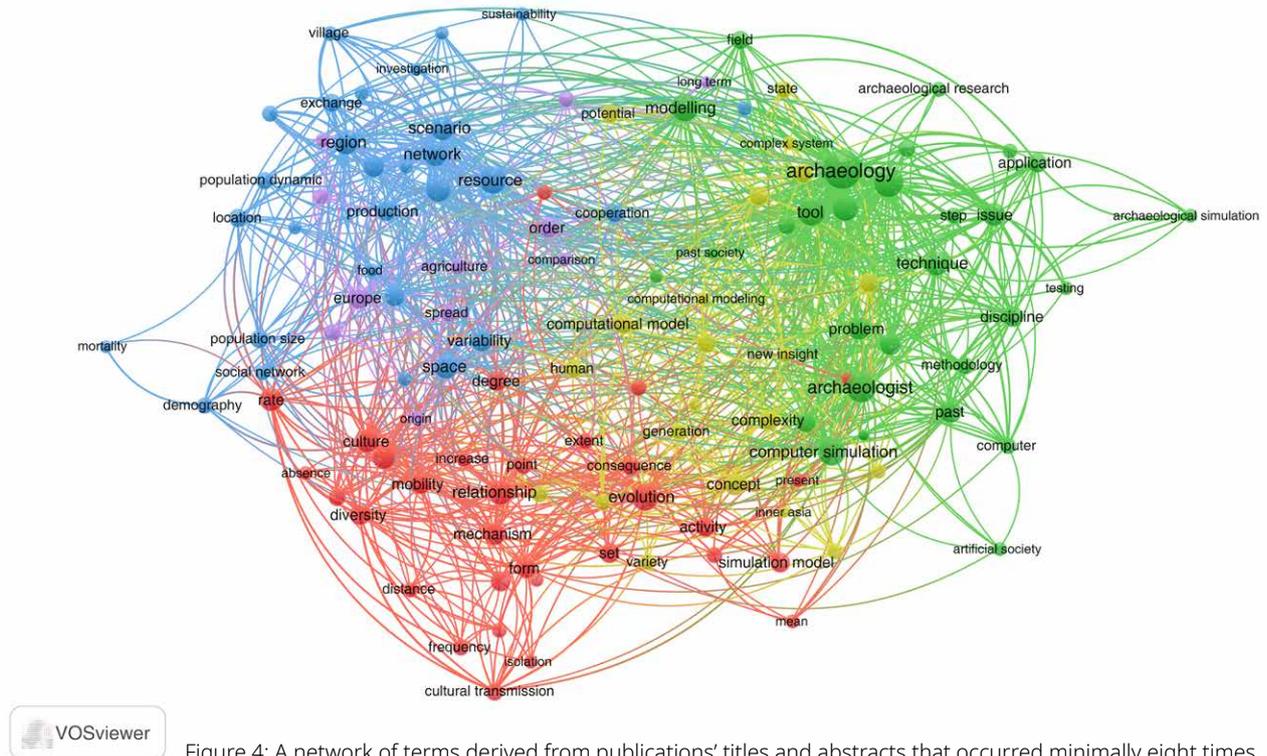


Figure 4: A network of terms derived from publications' titles and abstracts that occurred minimally eight times.

of publications over a decade and a half (Agapiou and Lysandrou 2015, fig. 1). The Google Ngram and Wikidata point to the early 2000s as the starting point of ABM meaning that archaeological ABM was off the starting blocks at a similar moment in time as in other disciplines, but failed to gain as much popularity as elsewhere (compare for example conservation studies: Ríos-Saldaña *et al.* 2018). It is hard to decide whether this can be decisively categorised as an “impasse” or is simply a slower uptake trajectory, nevertheless the often-repeated mantra of an “explosion” in archaeological ABM is a hyperbole rather than reality. Instead, the adoption of ABM in archaeology has been much less pronounced than its advocates may hope for and did not compare with its rise in popularity across other scientific disciplines.

3.2 Topics and terminology

A network of terms used in ABM papers reveals the popularity of different research topics and changes therein over time (table 1 and figure 4). The majority of ABM papers in archaeology fall within one of the five distinguishable clusters of terms:

1. Socionatural systems (as defined by Barton *et al.* 2012), where long-term dynamics between human

groups and their environment is explored (table 1, cluster 3; figure 4, the blue cluster);

2. Cultural evolution, and the related topics such as the origins and spread of innovation – (table 1, cluster 1; figure 4, the red cluster);
3. A cluster related to modelling the rise of hierarchical societies and social complexity (table 1, cluster 4; figure 5, the yellow cluster);
4. Neolithic spread in Europe – a particularly common modelling topic (table 1, cluster 5; figure 4, the purple cluster);
5. General modelling terminology, likely related to papers dedicated to the methodology, epistemology and history of archaeological ABM (the current paper would fall in this category) (table 1, cluster 2; figure 4, the green cluster).

If taken at a general level, the terms identified through the title and abstracts of publications show a high degree of homogeneity in archaeological ABM. The network is dense and the clusters are highly distributed with many terms used across most or all clusters. Not surprisingly certain words, namely “agent”, “model”, “simulation”, “archaeology”, etc. repeat in almost all publications. Nevertheless, it seems that the community has also developed a certain level of

| Cluster 1 | Cluster 2 | Cluster 3 | Cluster 4 | Cluster 5 |
|-----------------------|---------------------------|--------------------|-------------------------|--------------------|
| absence | abm | climate | adaptation | agriculture |
| activity | application | climate change | complex system | comparison |
| amount | archaeological research | cooperation | complexity | europa |
| consequence | archaeological simulation | demography | computational model | farming |
| cultural transmission | archaeological site | exchange | computational modelling | influence |
| culture | archaeologist | food | concept | long term |
| degree | archaeology | good | generation | modelling approach |
| distance | article | household | hierarchy | order |
| diversity | artificial society | investigation | human | origin |
| evolution | chapter | location | human society | spread |
| extent | computer | mortality | inner asia | transition |
| form | computer simulation | movement | interest | |
| frequency | discipline | network | new insight | |
| increase | field | person | organization | |
| innovation | issue | population dynamic | perspective | |
| isolation | methodology | population size | potential | |
| lack | modelling | presence | small scale society | |
| land use | nature | production | social complexity | |
| mean | past | region | state | |
| mechanism | past society | resilience | variety | |
| mobility | problem | resource | world | |
| point | researcher | scenario | | |
| possibility | social science | settlement | | |
| present | step | social network | | |
| rate | technique | space | | |
| relationship | tendency | success | | |
| set | testing | sustainability | | |
| simulation model | tool | variability | | |
| size | use | village | | |
| spatial distribution | | | | |
| transformation | | | | |
| variation | | | | |

Table 1: Clusters of terms identified in titles and abstracts of archaeological ABM publications.

unified vocabulary beyond them that enables them to quickly and efficiently describe the topic and the type of models they work on: cultural transmission, land use, social complexity, small scale society, network, population dynamics, etc. These terms also mirror the general types of research questions that are addressed with ABM, concerned with population-level societal issues, environment and landscape change, evolution, dynamics and interactions and align closely to standard scientific nomenclature in relevant disciplines, indicating that archaeologists do not “reinvent the wheel” but draw upon existing expertise. It is a key observation that archaeological terms describing time periods (*e.g.*, Neolithic, Roman), archaeological data types (*e.g.*, lithics, pottery) or particularly exhaustively researched sites (*e.g.*, Pompeii, Stonehenge, Mesa Verde) are not as common as these more general terms.

This may signal a simple fact that there have not been enough individual studies on any particular archaeological topic to cross the threshold but equally, it is likely to demonstrate the inherent interest of ABM modellers in archaeology in general patterns and dynamics of human societies, rather than individual instances of them. Thus, archaeological modelling is directly answering the calls for a shift in focus of archaeological research from individual sites towards better understanding of general patterns of human behaviour, adaptation and resilience (Barker *et al.* 2016, 6; Barton 2005; Kintigh *et al.* 2014). It is well-positioned to bring forward the agenda of “it is possible and necessary to learn from the past” and elevate the role of archaeology in finding solutions to current challenges.

A zoom-in onto two terms: “household” and “complexity” illustrates this point (figure 5). The first term derives from the very practical use of ABM in investigating the long-term evolution of settlement patterns, while the second shows its relationship to the theoretical framework of complexity theory and the goal of applying it to social systems. Here again, ABM reveals a promise of leveraging archaeological data to find deeper patterns that go beyond individual circumstances but rather reflect mechanisms that governed past and present human groups. While many ABM modellers focused on this type of “system theory” research, ABM can be used to investigate smaller-scale questions, for example, regarding a single site or a region. Perhaps some of the current impasse stems from the difference in goals between the majority of practising archaeologists who are predominantly interested in learning as much as possible about their object of study (which could be a site, a type of artefact, or a particular issue in a given

time period) and modellers who often come from the complexity science or systems thinking theoretical perspectives (Davies and Romanowska 2018).

3.3 Researchers in archaeological ABM

The co-authorship network shows the relationships between researchers who co-authored at least one publication together (figure 6). It is clear that the majority of ABM modellers in archaeology work alone or in small teams with limited mobility between them. It seems that working on specific projects requires more dedicated effort, which means that researchers work alone – in most cases serving as “the modeller” on an archaeological project team or within small teams focused on one research problem. The team around Tim Kohler’s lab (the Village Ecodynamics Project; Kohler *et al.* 2007) is the most connected crossing over to the Artificial Anasazi team (Axtell *et al.* 2002) and to researchers in Europe and Canada and also showing continuity across generations with researchers that then went on to develop their own modelling careers and started their own projects. Other clusters represent members of different individual projects, such as the Simulpast (Saiz *et al.* 2013), Finding the Limits of the Limes (Verhagen *et al.* 2019), the Celtic Oppidum project (Danielisova *et al.* 2015), the Hallstatt mining simulation project (Kowarik *et al.* 2015) and the Mediterranean Landscape Dynamics projects (Barton *et al.* 2010) or labs (research groups) such as the UCL group, Spanish groups centering on Barcelona’s institutions or the Arizona State group. Nevertheless, in most cases, ABM projects do not exchange or mix and match researchers and their mobility is limited.

The network of citations (figure 7; a link is drawn for any pair of authors that cited one another at least twice) further supports the observation that, while archaeological ABM modellers may not be working together, they are a coherent community without strong opposing “camps” or even clusters. This is partially because the group itself is small and has not fragmented into different subgroups focused on different topics as is naturally the case for larger research fields. This cohesion may result from strong interpersonal relationships, demonstrating the strengths of the community could counteract the negative repercussions of the fragmentation visible in the collaboration network (figure 6).

What is interesting is the lack of one or few “powerhouses” typical in most branches of science, where one or several research centres dominate the

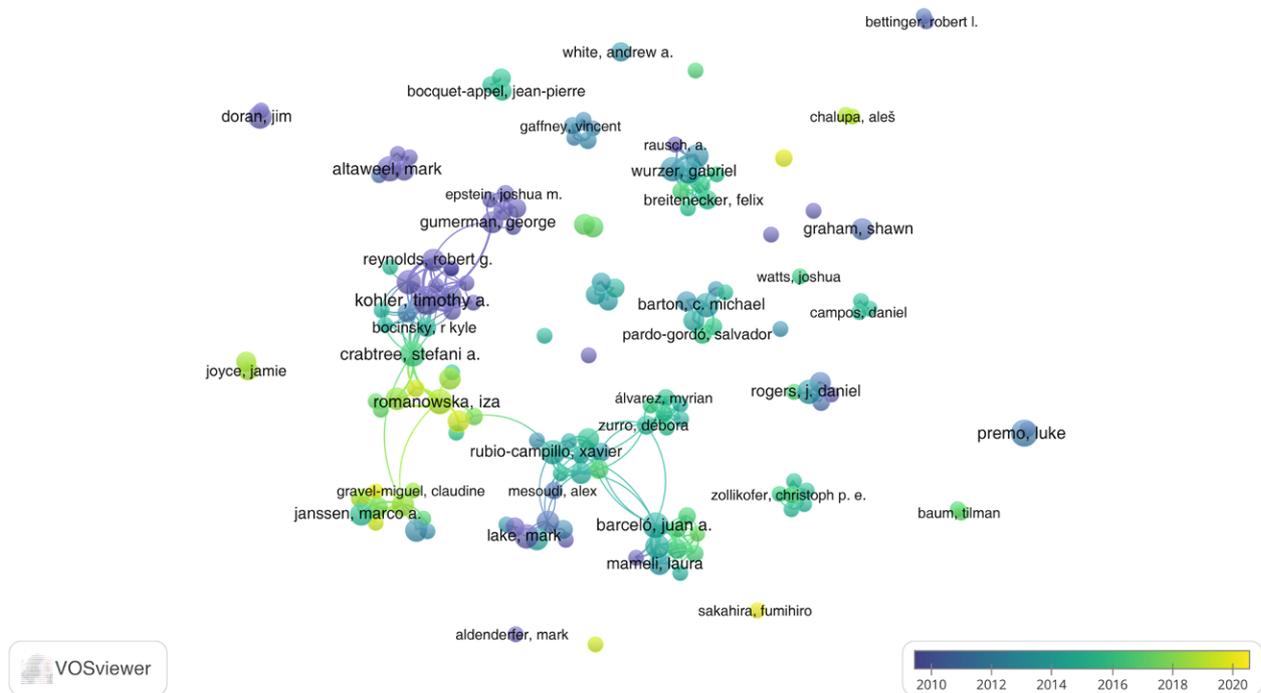


Figure 6: The co-authorship network. Each author has more than two ABM publications. Darker colours indicate older links, and lighter ones – more recent connections. Please note the time scale is focused on the years 2010 to 2018.

field, producing early career researchers, elaborating methods, questions and tools and generally driving the agenda in the particular field. Instead, archaeological ABM modellers seem to be spread thinly through existing archaeological structures (figure 6) showing that despite the suggestions to the contrary they are very much integrated within the discipline, while at the same time distinctive enough to form a community. This likely reflects the dual nature of archaeological simulation: on the one hand, it focuses on concrete archaeological questions (separating force) but on the other hand, all ABM modellers use the same technology, which makes their research relevant to one another (connecting force).

This is further supported through a look at the venues in which archaeological ABM modellers publish their studies (figure 8). The journals can be classified into three types: high-impact interdisciplinary journals (PNSA, PloS One), archaeological journals (American Antiquity, JAMT, JAS, JAA, etc) and journals focused on modelling (JASSS, Advances in Complex Systems) or modelling in other disciplines tangentially related to archaeology (Ecological Modelling, Land, Computational Social Sciences). In addition, the annual Proceedings of the Computer Applications

and Quantitative Methods in Archaeology (CAA) conference hosted a significant amount of ABM research (15 papers in total). The number of citations to American Antiquity and PNAS is partially due to the earlier start of archaeological ABM in the USA with the seminal early models of the groups that used to live in the American Southwest. However, it also shows that USA-based colleagues have succeeded in making an impact within archaeology among the non-modelling scholars (the number of citations is too high to be explained away by other modellers citing the studies). One should perceive this as a lesson on how to communicate and disseminate one's models to a wider archaeological audience.

4 DISCUSSION AND CONCLUSIONS

The historical patch of archaeological ABM initially mirrored closely the general trends, with the methods starting to pick up around the first years of the millennium. It has not followed the trajectory of ABM in other disciplines, though. While the adoption of simulation and ABM has been gaining momentum in other social and life sciences, in humanities it remained a niche activity. To reach this threshold of acceptance means that a new method starts to live on its own. The

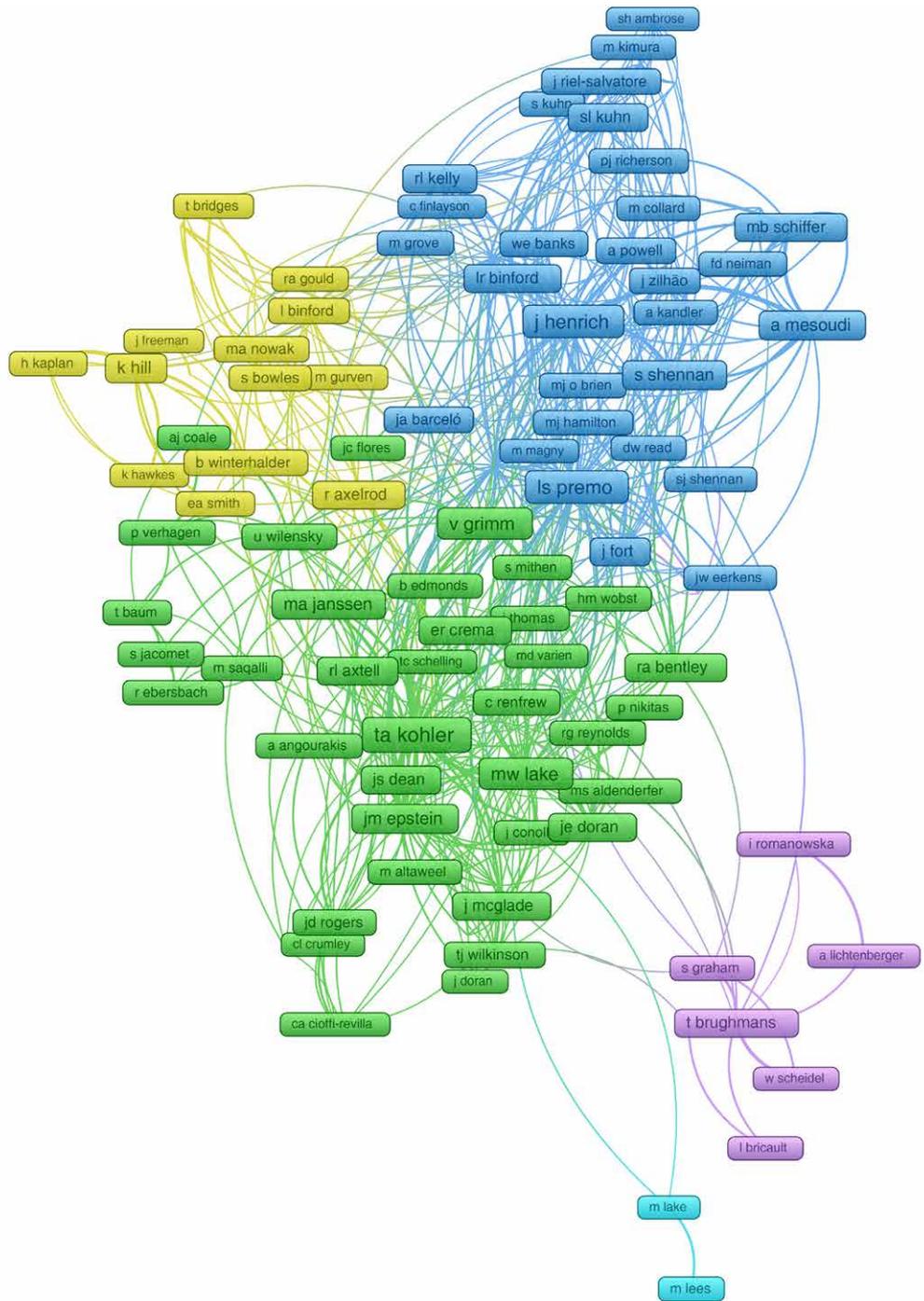


Figure 7: The co-citation network between archaeological ABM modellers. Note that some names may belong to non-modellers as they are paper co-authors.

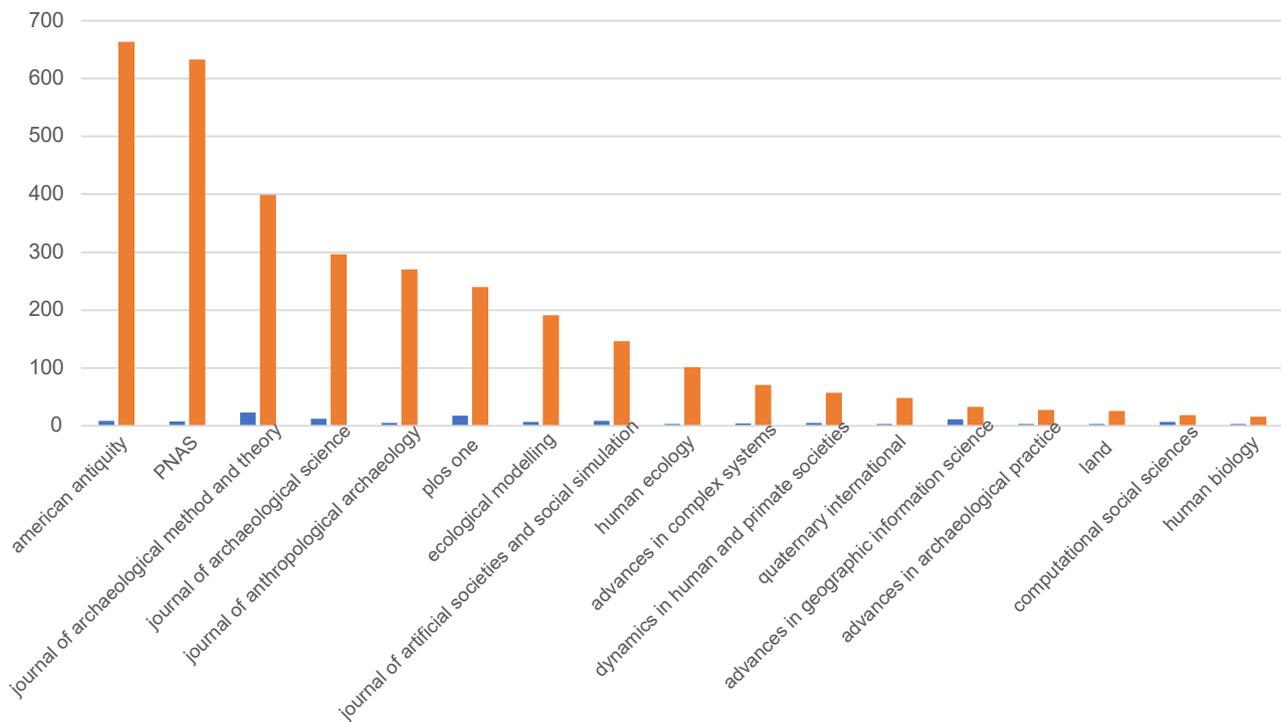


Figure 8: Graph showing frequency of publications (blue) and citations (orange) in academic journals.

more models are developed in social sciences, ecology, economy etc. the more accepted and respected the technique becomes and it is also easier to develop more coherent frameworks which, in turn, enable researchers to engage with the models in meaningful ways.

Much of the history of simulation studies and ABM in archaeology can be interpreted through periods of coincidence between theoretical trends favouring systemic analysis and societal-level questions and the development of computational tools facilitating implementation. Lake (2014; 2015) comprehensively describes the history of archaeological simulation noting two distinctive phases when such coincidence occurred. The early applications of simulation in the 1970s were fuelled by the increasingly available and “usable” computers and related to systems theory (New Archaeology) dominating archaeology at the time. The renaissance of simulation studies, predominantly through the rise of ABM, dating to the beginning of the new millennium can be linked to the spreading popularity of complexity science coupled with the appearance of ABM-friendly coding platforms, including NetLogo in 1999.

It seems, therefore, that for simulation to thrive two conditions need to be fulfilled: the *need* for it and the *means* of conducting it. The *need* relates to

research questions that match the technique while the *means* amount to computational tools that are within the reach of archaeologists. It has been repeatedly argued that the reason for it is the high level of technical skill necessary, which requires a substantial investment in skill acquisition to get to an adequate level of coding proficiency. Thus episodes of coincidence of these two factors are not common. The personal opinion of the authors is that currently, both of these conditions are somewhat fulfilled. The NetLogo environment provides a relatively easy-to-learn modelling framework (*the means*) and there is some interest in generalised *longue-durée* trends in the histories of past societies (*the need*). Nevertheless, even NetLogo requires coding skills which are not common among archaeologists, and only a small proportion of them are actively interested in the kind of topics typical for simulation. Thus, despite the high level of optimism in the last couple of decades archaeological simulation remains a niche activity limited to those enthusiastic enough to invest the time and effort into mastering the necessary technical skills. Only a handful of institutions incorporated simulation in their curricula, the number of papers presenting simulation studies is relatively stable and while papers involving simulation and ABM appear at

conferences they usually cluster in dedicated sessions and specialised, usually digital or computational archaeology, events. While there is nothing inherently wrong in this situation, simulation is a form of theory building and as such should be regarded as part of the disciplinary evolution and a critical element of theory development and testing rather than a technological gadget. The value of formal models is in that they support cumulative knowledge building where with each new study we get closer and closer to the truth. This only happens through constant questioning and testing of existing models against alternative representations (new models) and new data. The process of modelling, therefore, falls into the remit of domain specialists and should not be restricted to a separate community.

There are likely several reasons as to why archaeology has, so far, not embraced ABM and simulation to the same degree as other related disciplines. First and foremost, there is a distinctive lack of formal modelling tradition in humanities. Where in ecology or social sciences, such as economy many theories and hypotheses have in the past and now often been presented in formal, either mathematical or formal logical, manner, this has never been a dominant part of humanities research culture. Here storytelling, narrative building and juxtapositions of arguments in verbal discourse are the dominant methods for theory building. This poses an intrinsic difficulty of translating theory into computer code (Brughmans *et al.* 2019) – an obstacle that other disciplines experience to a far lesser degree.

Another major difference is the societal role of the discipline and how it is perceived. Despite the fact that archaeology matters to communities and individuals, the truth is archaeological research projects have far fewer real-world consequences and especially those that can be easily measured and quantified. This means that archaeologists are under significantly less pressure to provide explicit, well-defined and testable models compared to social scientists, economists or ecologists whose work translates into policy making. Conceptual models presented as narratives are generally accepted in the discipline.

Despite these caveats, archaeological simulation modelling is growing, albeit slowly. Perhaps the “impasse” will be overcome when enough archaeologists will have the *means* (i.e., programming skills) to quickly and efficiently develop their own models or to be able to read existing ones. With the ongoing shift towards increasingly dominant data-driven research

in archaeology (Huggett 2020; Kansa and Kansa 2021; Schlanger *et al.* 2015) it is easy to imagine that a similar transformation for theory building and testing may be waiting just around the corner. In our opinion for this to happen the following four conditions need to be met:

1. Focus on education.

In many scientific disciplines, practitioners make models to describe and explain phenomena they study. For example in physics, the construction of models is a basic teaching objective from the first introductory courses onwards (Etkina *et al.* 2006). We argue that humanities should follow this path and add introductory courses to their curriculum to ensure practitioners can meaningfully and critically engage with published models (cp. Scherjon *et al.* 2019). For example, nowadays virtually all archaeological departments ordinarily train their students in GIS. As a result of introductory courses being part of the standards curriculum, a much higher percentage of practitioners has a good understanding of the methods and their outputs even if the technique remains a specialised activity undertaken by only some practitioners.

2. Shift towards more systemic research questions.

As previously mentioned, research questions that lend themselves to computational modelling are a prerequisite for ABM to grow and thrive. With a constantly growing number of open access datasets and repositories (Kintigh 2006; Richards 2021), large projects bringing together previously disjointed data and increasingly standardised methods for recording and managing archaeological data, the comparative objective of archaeology is flexing its muscle (Altschul *et al.* 2018; Wright and Richards, 2018). Big questions became possible for researchers to attack (D’Alpoim Guedes *et al.* 2016; Kohler *et al.* 2017; Smith *et al.* 2021) and while the large-scale comparative data analysis is opening new avenues of research, it will also require capacity in formal modelling methods to identify and understand dynamic processes that drove social and socio-natural systems.

3. Expectation at theory building to be conducted formally.

Archaeology is increasingly shifting from individual small project and personal research towards

multidisciplinary team-driven large-scale and multi-year projects and labs. This shift should be accompanied with an expectation that theory building and hypothesis testing should be formally executed, *i.e.*, through such means as mathematical description, computational models or using formal logic. Not only will it ensure that the research questions posed are testable and can be addressed within the existing scientific methods but also it will greatly facilitate interdisciplinary collaboration. A formal model lets project leaders draw all the available evidence derived from different types of data into one coherent and robust framework.

4. Well-designed communication and dissemination of models, their results and implications for the understanding of the past.

Stronger emphasis on transparent and reproducible science helps the ABM cause. A theory defined in natural language is neither transparent nor reproducible for anyone other than its author. In archaeology, we champion the obligation to make data and methods available for other researchers to see and examine (Marwick *et al.* 2017). The same should apply to their theories and models. Even if the model's code is available for inspection and critique, it requires technical know-how to meaningfully do so. Similar to other branches of archaeology (carbon-14 dating, isotope studies) this can be undertaken by specialists in this domain, and not necessarily by everyone interested in the results. At the same time, modelling results need to be communicated clearly and accessible for anyone without a strong computational background to be able to question the model's ontology and assumption. This often places modellers at a disadvantage since their transparent, fully specified models can be inspected and critiqued to a much higher degree than verbally formulated hypotheses. Here, the first point regarding archaeology-wide education comes back. Archaeological non-modellers need to understand the role of modelling in the scientific process to engage meaningfully with formal models such as ABM.

Not taking this path of stronger formalisation of the archaeological practice may prove dangerous. In the world of evidence driven decision making, traditional narratives and anecdotal evidence do not meet the necessary threshold for rigour. Archaeology may unnecessarily lose a part of its societal value if we do not produce testable and rigorously developed

models that can be convincingly presented to the public and policy makers. The infrequent use of formal modelling tools is unnecessarily limiting the value of archaeological research to the real world, where it could significantly contribute to our understanding of the past and to solving some of the current societal challenges. It may be a long-term goal but definitely worth setting.

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REFERENCES

- Agapiou, A., and V. Lysandrou. 2015. "Remote Sensing Archaeology: Tracking and Mapping Evolution in European Scientific Literature from 1999 to 2015." *Journal of Archaeological Science: Reports* 4 (December): 192-200. DOI:10.1016/j.jasrep.2015.09.010.
- Altschul, J.H., K.W. Kintigh, T.H. Klein, W.H. Doelle, K.A. Hays-Gilpin, S.A. Herr, T.A. Kohler, B.J. Mills, L.M. Montgomery, M.C. Nelson, S.G. Ortman, J.N. Parker, M.A. Peeples and J.A. Sabloff. 2018. "Fostering Collaborative Synthetic Research in Archaeology." *Advances in Archaeological Practice* 6 (1): 19-29. DOI:10.1017/aap.2017.31.
- Axtell, R.L., J.M. Epstein, J.S. Dean, G.J. Gumerman, A.C. Swedlund, J. Harburger, S. Chakravarty, R. Hammond, J. Parker, and M. Parker. 2002. "Population Growth and Collapse in a Multiagent Model of the Kayenta Anasazi in Long House Valley." *Proceedings of the National Academy of Sciences of the United States of America* 99 (Suppl 3): 7275-79.
- Barker, G., C. Roberts, C. Gosden, A. Horning, and K. Welham. 2016. "Reflections on Archaeology." London: British Academy. <https://www.thebritishacademy.ac.uk/publications/reflections-archaeology/>.
- Barton, C.M., I.I. Ullah, and S.M. Bergin. 2010. "Land Use, Water and Mediterranean Landscapes: Modelling Long-Term Dynamics of Complex Socio-Ecological Systems." *Philosophical Transactions of the Royal Society A: Mathematical, Physical and Engineering Sciences* 368 (1931): 5275-97. DOI:10.1098/rsta.2010.0193.
- Barton, C.M., I.I. Ullah, S.M. Bergin, H. Mitasova, and H. Sarjoughian. 2012. "Looking for the Future in

- the Past: Long-Term Change in Socioecological Systems.” *Ecological Modelling* 241 (August): 42-53. DOI:10.1016/j.ecolmodel.2012.02.010.
- Barton, M. 2005. “Stories of the Past or Science of the Future? Archaeology and Computational Social Science.” In *Computational Approaches to Archaeological Spaces*, edited by A. Bevan and M. Lake, 151-78. Walnut Creek: Left Coast Press.
- Brughmans, T., J.W. Hanson, M.J. Mandich, I. Romanowska, X. Rubio-Campillo, S. Carrignon, S. Collins-Elliott, K. Crawford, D. Daems, F. Fulminante, T. de Haas, P. Kelly, M. del Carmen Moreno Escobar, E. Paliou, L. Prignano and M. Ritondale. 2019. “Formal Modelling Approaches to Complexity Science in Roman Studies: A Manifesto.” *Theoretical Roman Archaeology Journal* 2 (1): 4. DOI:10.16995/traj.367.
- Crabtree, S.A., K. Harris, B. Davies, and I. Romanowska. 2019. “Outreach in Archaeology with Agent-Based Modeling: Part 3 of 3.” *Advances in Archaeological Practice* 7 (2): 194-202. DOI:10.1017/aap.2019.4.
- Crooks, A.T., and A.J. Heppenstall. 2012. “Introduction to Agent-Based Modelling.” In *Agent-Based Models of Geographical Systems*, edited by A.J. Heppenstall, A.T. Crooks, L.M. See, and M. Batty, 85-105. Dordrecht: Springer Netherlands. DOI:10.1007/978-90-481-8927-4_5.
- D’Alpoim Guedes, J., S. Crabtree, R.K. Bocinsky, and T. Kohler. 2016. “Twenty-First Century Approaches to Ancient Problems: Climate and Society.” *Proceedings of the National Academy of Sciences* 113 (December). DOI:10.1073/pnas.1616188113.
- Danielisova, A., K. Olsevicova, R. Cimler, and T. Machalek. 2015. “Understanding the Iron Age Economy: Sustainability of Agricultural Practices under Stable Population Growth.” In *Agent-Based Modeling and Simulation in Archaeology*, edited by Gabriel Wurzer, Kerstin Kowarik, and Hans Reschreiter, 183-216. Advances in Geographic Information Science. Cham: Springer International Publishing. DOI:10.1007/978-3-319-00008-4_9.
- Davies, B., and I. Romanowska. 2018. “An Emergent Community? Agent-Based Modelers in Archaeology.” *The SAA Archaeological Record* 18 (2): 27-32.
- Davies, B., I. Romanowska, K. Harris, and S.A. Crabtree. 2019. “Combining Geographic Information Systems and Agent-Based Models in Archaeology: Part 2 of 3.” *Advances in Archaeological Practice* 7 (2): 185-93. DOI:10.1017/aap.2019.5.
- De Bellis, N., 2009. “Bibliometrics and Citation Analysis: From the Science Citation Index to Cybermetrics.” Lanham, MD: The Scorecrow Press, Inc.
- De Domenico, M., and H. Sayama. 2019. “Complexity Explained.” DOI:10.17605/OSF.IO/TQGNW.
- Dubois, G. 2018. *Modeling and Simulation Challenges and Best Practices for Industry: Challenges and Best Practices for Industry*. Boca Raton: CRC Press. DOI:10.1201/9781351241137.
- Etkina, E, A. Warren, and M. Gentil. 2006. “The Role of Models in Physics Instruction.” *The Physics Teacher* 44(1): 34-3.
- Gilbert, G.N., and K.G. Troitzsch. 2011. *Simulation for the Social Scientist*. Maidenhead: Open University Press.
- Hamill, L., and N. Gibert. 2016. *Agent Based Modelling in Economics*. Chichester: Wiley.
- Hartmann, S. 1996. “The World as a Process. Simulations in the Natural and Social Sciences.” In *Modelling and Simulation in the Social Sciences from the Philosophy of Science Point of View*, edited by Rainer Hegselmann, Ulrich Mueller, and Klaus G. Troitzsch, 77-100. Dordrecht: Springer Netherlands. DOI:10.1007/978-94-015-8686-3_5.
- Huggett, J. 2020. “Is Big Digital Data Different? Towards a New Archaeological Paradigm.” *Journal of Field Archaeology* 45 (sup1): S8-17. DOI:10.1080/00934690.2020.1713281.
- Kansa, E., and S. Whitcher Kansa. 2021. “Digital Data and Data Literacy in Archaeology Now and in the New Decade.” *Advances in Archaeological Practice* 9 (1): 81-85. DOI:10.1017/aap.2020.55.
- Kintigh, K.W. 2006. “The Promise and Challenge of Archaeological Data Integration.” *American Antiquity* 71 (3): 567-78. DOI:10.2307/40035365.
- Kintigh, K.W., J.H. Altschul, M.C. Beaudry, R.D. Drennan, A.P. Kinzig, T.A. Kohler, W.F. Limp, H.D.G. Maschner, W.K. Michener, T.R. Pauketat, P. Peregrine, J.A. Sabloff, T.J. Wilkinson, H.T. Wright, and M.A. Zeder. 2014. “Grand Challenges for Archaeology.” *Proceedings of the National Academy of Sciences of the United States of America* 111 (3): 879-80. DOI:10.1073/pnas.1324000111 .
- Kohler, T.A., C. Johnson, M.D. Varien, S.G. Ortman, R.G. Reynolds, Z. Kobti, J. Cowan, K. Kolm, S. Smith, and L. Yap. 2007. “Settlement Ecodynamics in the Prehispanic Central Mesa Verde Region.” In *The Model-Based Archaeology of Socionatural Systems*, edited by Timothy A. Kohler and Sander Ernst van der Leeuw, 61-104.

- Kohler, T.A., M.E. Smith, A. Bogaard, G.M. Feinman, C.E. Peterson, A. Betzenhauser, M. Pailes, E.C. Stone, A.M. Prentiss, T.J. Dennehy, L.J. Ellyson, L.M. Nicholas, R.K. Faulseit, A. Styring, J. Whitlam, M. Fochesato, T.A. Foor, and S. Bowles. 2017. "Greater Post-Neolithic Wealth Disparities in Eurasia than in North America and Mesoamerica." *Nature* 551 (7682): 619-22. DOI: 10.1038/nature24646.
- Kowarik, K., H. Reschreiter, and G. Wurzer. 2015. "Mining with Agents: Modelling Prehistoric Mining and Prehistoric Economy." In *Agent-Based Modeling and Simulation in Archaeology*, edited by Gabriel Wurzer, Kerstin Kowarik, and Hans Reschreiter, 141-59. Cham: Springer International Publishing. http://link.springer.com/10.1007/978-3-319-00008-4_7.
- Lake, M.W. 2008. "Computer Simulation Modeling." In *Encyclopedia of Archaeology*, 1034-40. Elsevier. DOI: 10.1016/B978-0-12373962-9.00027-3.
- Lake, M.W. 2014. "Trends in Archaeological Simulation." *Journal of Archaeological Method and Theory* 21: 258-87. DOI: 10.1007/s10816-013-9188-1.
- Lake, M.W. 2015. "Explaining the Past with ABM: On Modelling Philosophy." In *Agent-Based Modeling and Simulation in Archaeology*, edited by Gabriel Wurzer, Kerstin Kowarik, and Hans Reschreiter, 3-35. Advances in Geographic Information Science. Cham: Springer International Publishing. DOI: 10.1007/978-3-319-00008-4_1.
- Leonelli, M. 2021. "Simulation and Modelling to Understand Change." https://bookdown.org/manuele_leonelli/SimBook/.
- Marshakova, I. 1973. "System of documentation connections based on references (SCI)." *Nauchno-Tekhnicheskaya Informatsiya Seriya* 2(6): 3-8.
- Marwick, B., J. d'Alpoim Guedes, C.M. Barton, L.A. Bates, M. Baxter, A. Bevan, E.A. Bollwerk, R.K. Bocinsky, T. Brughmans, A.K. Carter, C. Conrad, D.A. Contreras, S. Costa, E.R. Crema, A. Daggett, B. Davies, B.L. Drake, T.S. Dye, P. France, R. Fullagar, D. Giusti, S. Graham, M.D. Harris, J. Hawks, S. Heath, D. Huffer, E.C. Kansa, S. Witcher Kansa, M.E. Madsen, J. Melcher, J. Negre, F.D. Neiman, R. Opitz, D.C. Orton, P. Przystupa, M. Raviele, J. Riel-Salvatore, P. Riris, I. Romanowska, N. Strupler, I.I. Ullah, H.G. Van Vlack, E.C. Watrall, C. Webster, J. Wells, J. Winters, and C.D. Wren. 2017. "Open Science in Archaeology." *The SAA Archaeological Record* 17 (4): 8-14. DOI: 10.17605/OSF.IO/3D6XX.
- McCain, K.W. 1991. "Mapping economics through the journal literature: An experiment in journal cocitation analysis." *Journal of the American Society for Information Science* 42(4): 290-296.
- Melchiorson, P.M. 2019. "Bibliometric Differences – a Case Study in Bibliometric Evaluation across SSH and STEM." *Journal of Documentation* 75 (2): 366-78. DOI: 10.1108/JD-07-2018-0108.
- Michel, J., Y.K. Shen, A.P. Aiden, A. Veres, M.K. Gray, The Google Books Team, J.P. Pickett, D. Hoiberg, D. Clancy, P. Norvig, J. Orwant, S. Pinker, M.A. Nowak, and E. Lieberman Aiden. 2011. "Quantitative Analysis of Culture Using Millions of Digitized Books." *Science* 331 (6014): 176-82. DOI: 10.1126/science.1199644.
- Poisot, T., R. LaBrie, E. Larson, A. Rahlin, and B.I. Simmons. 2019. "Data-Based, Synthesis-Driven: Setting the Agenda for Computational Ecology." *Ideas in Ecology and Evolution* 12 (July). DOI: 10.24908/iee.2019.12.2.e.
- Premo, L.S. 2006. "Agent-Based Models as Behavioral Laboratories for Evolutionary Anthropological Research." *Arizona Anthropologist* 17: 91-113.
- Premo, L.S. 2010. "Equifinality and Explanation: The Role of Agent-Based Modeling in Postpositivist Archaeology." In *Simulating Change. Archaeology into the Twenty-First Century*, edited by Andre Costopoulos and Mark Lake, Foundation, 28-37. Salt Lake City: University of Utah Press.
- Railsback, S.F., and V. Grimm. 2011. *Agent-Based and Individual-Based Modeling: A Practical Introduction*. Princeton: Princeton University Press.
- Richards, J.D. 2021. "Archiving Archaeological Data in the United Kingdom." *Internet Archaeology*, May. DOI: 10.11141/ia.58.21.
- Ríos-Saldaña, C.A., M. Delibes-Mateos, and C.C. Ferreira. 2018. "Are Fieldwork Studies Being Relegated to Second Place in Conservation Science?" *Global Ecology and Conservation* 14 (April): e00389. DOI: 10.1016/j.gecco.2018.e00389.
- Rogers, J.D., and W.H. Cegielski. 2017. "Opinion: Building a Better Past with the Help of Agent-Based Modeling." *Proceedings of the National Academy of Sciences* 114 (49): 12841-44. DOI: 10.1073/pnas.1718277114.
- Romanowska, I. 2015. "So You Think You Can Model? A Guide to Building and Evaluating Archaeological Simulation Models of Dispersals." *Human Biology Open Access* 87 (3): 169-92.
- Romanowska, I., S.A. Crabtree, K. Harris, and B. Davies. 2019. "Agent-Based Modeling for Archaeologists:

- Part 1 of 3.” *Advances in Archaeological Practice* 7 (2): 178-84. DOI:10.1017/aap.2019.6.
- Romanowska, I., C.D. Wren, and S.A. Crabtree. 2021. *Agent-Based Modeling for Archaeology: Simulating the Complexity of Societies*. Santa Fe: SFI Press.
- Saiz, J.C., D.Zurro, B. Rondelli, A.L. Balbo, X. Rubio-Campillo, J.A. Barceló, I. Briz i Godino, J. Fort, and M. Madella. 2013. “SimulPast: un laboratorio virtual para el análisis de las dinámicas históricas: SimulPast: a virtual lab to analyse historical dynamics.” *Archeologia e Calcolatori* 24: 265-81.
- Scherjon, F., Romanowska, I. and K. Lambers, 2019. “Digitally Teaching Digital Skills: Lessons Drawn from a Small Private Online Course (SPOC) on ‘Modelling and Simulation in Archaeology’ at Leiden University.” *Journal of Computer Applications in Archaeology* 2(1): 79-88. DOI:10.5334/jcaa.26
- Schlanger, S., R. Wilshusen, and H. Roberts. 2015. “From Mining Sites to Mining Data: Archaeology’s Future.” *KIVA* 81 (1-2): 80-99. DOI:10.1080/00231940.2015.1118739.
- Smith, M.E., J. Lobo, M.A. Peeples, A.M. York, B.W. Stanley, K.A. Crawford, N. Gauthier, and A.C. Huster. 2021. “The Persistence of Ancient Settlements and Urban Sustainability.” *Proceedings of the National Academy of Sciences* 118 (20): e2018155118. DOI:10.1073/pnas.2018155118.
- Sterman, J.D. 2000. *Business Dynamics. System Thinking and Modeling for a Complex World*. Boston: McGraw-Hill Higher Education.
- Székely, T., and K. Burrage. 2014. “Stochastic Simulation in Systems Biology.” *Computational and Structural Biotechnology Journal* 12 (20): 14-25. DOI:10.1016/j.csbj.2014.10.003.
- Van Eck, N.J., and L. Waltman. 2009. “Vosviewer: A computer program for bibliometric mapping.” *SSRN Scholarly Paper*. Rochester, NY: Social Science Research Network.
- Van Eck, N.J., and L. Waltman. 2011. “Text mining and visualization using VOSviewer.” *ISSI Newsletter* 7(3): 50-54.
- Van Eck, N.J. and L. Waltman. 2014. “Visualizing bibliometric networks.” In Y. Ding, R. Rousseau, and D. Wolfram (Eds.), *Measuring scholarly impact: Methods and practice*, pp. 285-320. New York: Springer.
- Verhagen, P., J. Joyce, and M. Groenhuijzen. 2019. *Finding the Limits of the Limes: Modelling Demography, Economy and Transport on the Edge of the Roman Empire*. New York, NY: Springer Science+Business Media.
- Wilensky, U. 1999. *NetLogo*. Evanston: Center for Connected Learning and Computer-Based Modeling, Northwestern University. <http://ccl.northwestern.edu/netlogo/>.
- White, H.D., and B. C. Griffith. 1981. “Author cocitation: A literature measure of intellectual structure.” *Journal of the American Society for Information Science* 32(3): 163-171.
- Wright, H., and J.D. Richards. 2018. “Reflections on Collaborative Archaeology and Large-Scale Online Research Infrastructures.” *Journal of Field Archaeology* 43 (sup1): S60-67. DOI:10.1080/00934690.2018.1511960.

Critical Miss? Archaeogaming as a Playful Tool for Archaeological Research and Outreach

Aris Politopoulos and Angus Mol

1 INTRODUCTION

Let's begin this chapter with a gaming analogy: archaeogaming has 'just been released' in archaeology, yet it already requires patching. Archaeogaming's roots can be found in 2013 (Reinhard 2013), although papers exploring the intersection of games and archaeology had been published earlier (Gardner 2007a; Morgan 2009). For such a recent field of study – and one that could be described as coming out of left field for most non-gaming academics – having archaeogaming included in a collection of critical reviews about digital archaeology is already a success in itself. Yet, it is exactly because archaeogaming is still so 'young', at least academically speaking, that we think it is important to identify and discuss shortcomings and impasses that might have developed over these early years. We will describe below how we will do this, but first we would like to share our own perspective on what archaeogaming is about to give some context to our critiques.

In a recent paper we offered the following definition of archaeogaming: [it is] *a movement born in and out of playful and digital scholarship [...] the fun of sharing a (scholarly) playground, one that is itself constructed or built in digital playgrounds* (Politopoulos *et al.* 2019). So, for us, archaeogaming is a scholarly undertaking – whether it is undertaken by professional archaeologists or other citizens who take a deeper interest in the intersections between the past and play. It is thus a mode of acquiring knowledge about how we playfully (re-)create and experience the past, and sharing that knowledge at least partly through the same practice, playful and digital in nature.

It is crucial to understand that archaeogaming is an endeavour that started as and still is powered by the fun we (the more than 2 billion video game players globally and its subset of professional archaeologists) have playing games. We use fun here as a broad concept defined by philosopher and video game designer Ian Bogost, as anything related to with commitment, attention, and care (Bogost 2016, 33). To be specific, we argue that a committed, attentive, and caring relation with the past and play is therefore at the core of archaeogaming (Politopoulos and Mol 2021). Fun, however, is rarely considered (wrongly so, in our opinion) to have academic value. If the core of archaeogaming is not 'academic enough' and needs to become 'rigorous', 'serious', 'data-driven', 'method-focused', or 'more theoretical', it will be alienated from its own driving force: having fun with the past and games. On the other hand, we have grown to realize there is such a thing as having 'too much fun'. In our conceptualization, this would entail a relation that is overcommitted, over-attentive, or even self-indulgent. In practice, such a negative relation could take many forms: for example, to us it could mean turning

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away from being a (digital) archaeology movement to becoming a contained (sub)discipline of specialists whose core concerns cannot be understood by most others – a blend of archaeology and video game nerds. It is in this sliding scale from ‘should not be (about)’ to ‘being too much’ fun that archaeogaming can be a slippery tool, and this will form the underlying grid of our critique here.

We have been involved with archaeogaming as individuals, researchers, and founding members of the VALUE Foundation from very early on, and have developed several research and outreach projects as well as four international conferences.¹ As such, we first and foremost feel that it is important to be reflective and critical of our own work. For each vector of our critique, we will therefore first and foremost be looking at our own critical misses. We will also be looking at other projects and output, with the goal of ‘punching’ up, or at the very least sideways. This is important, as it is not our goal to be destructively critical of this budding field of research, let alone of up-and-coming scholars within it, but rather to be reflective of what has been done so far and can be considered as ‘established’ within archaeogaming. For each different point of critique, we will also be offering a best practice: individuals or groups that we think have been particularly fruitful or promising in their approaches. The vectors of our critique will be archaeogaming as a tool for: i) the study of games; ii) archaeological outreach; and iii) building bridges between disciplines.

2 AN ARCHAEOGAMING REVIEW

To understand why we believe that archaeogaming is in crisis, or in fact in multiple crises, we must offer some more context. In particular, we will discuss the dynamics that have led to these inflection points.

2.1 The Early Stages

The engagement of archaeologists with video games had already begun before the term ‘archaeogaming’ was coined. Andrew Gardner was the first to publish a discussion on the representation of the past in video games from an archaeological perspective (Gardner 2007b).

1 VALUE at the time stood for Videogames and Archaeology at Leiden University, where the founding members were all located at the time. Admittedly we had to stretch the acronym to work. The VALUE Foundation has retained the name, but not as an acronym.

Colleen Morgan used the video game *Second Life* as an experimental space to recreate a virtual Çatalhöyük (Morgan 2009). Although Morgan’s paper was less about the ‘game’ aspect, focusing more on the reconstruction as an ongoing and multivocal experiment of the representation of archaeological sites in virtual spaces, it remains one of the most influential and successful applications of video games in archaeological research.

Erik Champion has also been one of the first and most influential individuals on the topic of virtual spaces, virtual heritage, and the past. In particular, he discussed the potential (but also the potential issues) of interactive digital visualizations of the past for outreach, education, and awareness, introducing such concepts as virtual tourism and the virtual traveller (Champion 2011; 2015).

What is broadly termed as *archaeogaming*, however, did not start in academic outlets, but rather as a grassroots initiative in the blog and Twitter spheres. Andrew Reinhard coined the term for his namesake blog *Archaeogaming* in 2012. He used this blog as a space to write small pieces on the connections he found between games and archaeology. Although, initially, Reinhard was a rather reluctant gamer, it was through the rich worlds he found in games, and their own dedicated pasts, that he kept gaming, which made him realize that such spaces have the potential to be studied archaeologically (Reinhard 2013).

One of the first blogs to highlight the connection between video games and archaeology was Shawn Graham’s *Electric Archaeology*. He had been involved for quite some time with the use of games and the telling of the past both in academic outlets (Kee *et al.* 2009) and in education (Graham 2012). Graham, much like Reinhard, felt the need to explain why he plays games (and we will return to this point later). He argued that “*I play because I enjoy video games, obviously, but I also get something out of it. [...] Because it makes me think differently about the materials I encounter*” (Graham 2013). At the same time, Graham was also involved with the *Play the Past* blog, a collective of historians, archaeologists, and heritage and media studies professionals that dealt with the past in games, from history (*e.g.*, Hussey 2013) to linguistics (Travis 2011) to archaeology (Politopoulos 2014a).

Another important blog was *Gamingarchaeo*. This now-inactive site was used by former professional gamer and archaeologist Tara Copplestone as an outlet for exploring the connection between games (and game development in particular) and archaeology. In her

MA thesis, Copplestone conducted ground-breaking research on the historical design of the *Assassin's Creed* series (Copplestone 2014). She was also involved in several game jams (short game development competitions), being one of the first individuals in archaeogaming to use the interactive narrative development tool Twine to create archaeologically themed, hypertext-based games (see for example the game *Buried* [Copplestone and Botham 2014]). Somewhat later, Meghan Dennis developed the also-inactive blog *Gingerygamer*, dealing with ethics and archaeology in video games, based on her PhD project.

In 2015 the authors, together with Csilla Ariese, Krijn Boom, and Vincent Vandemeulebroucke, developed the VALUE Project at Leiden University, following a lecture by Aris Politopoulos at the Archaeological Forum of the Faculty of Archaeology (Politopoulos 2014b). Among other things, this led to us developing the VALUE project blog in 2015, which eventually became the *Interactive Pasts* blog in 2016. The blog curates archaeologically themed video game reviews, has a bulletin with news on video games and the past, and offers in-depth analyses of video games in relation to archaeological/historical themes.

In addition to blogs, in these early stages the discussion mainly took place via social media, and particularly Twitter. Using *#archaeogaming*, archaeologists – both students and young researchers – and enthusiasts alike engaged in conversations about their passion, generating a lot of new ideas. One of these ideas was the Archaeogaming Unconference, which was organized in 2015 and again in 2017 by Shawn Graham and Tara Copplestone (Graham 2015; 2017a). The VALUE Project also organized the first ever in-person archaeogaming conference, the *Interactive Pasts Conference*, in 2017 (Mol *et al.* 2017a).²

2.2 Archaeogaming and digital Archaeology research

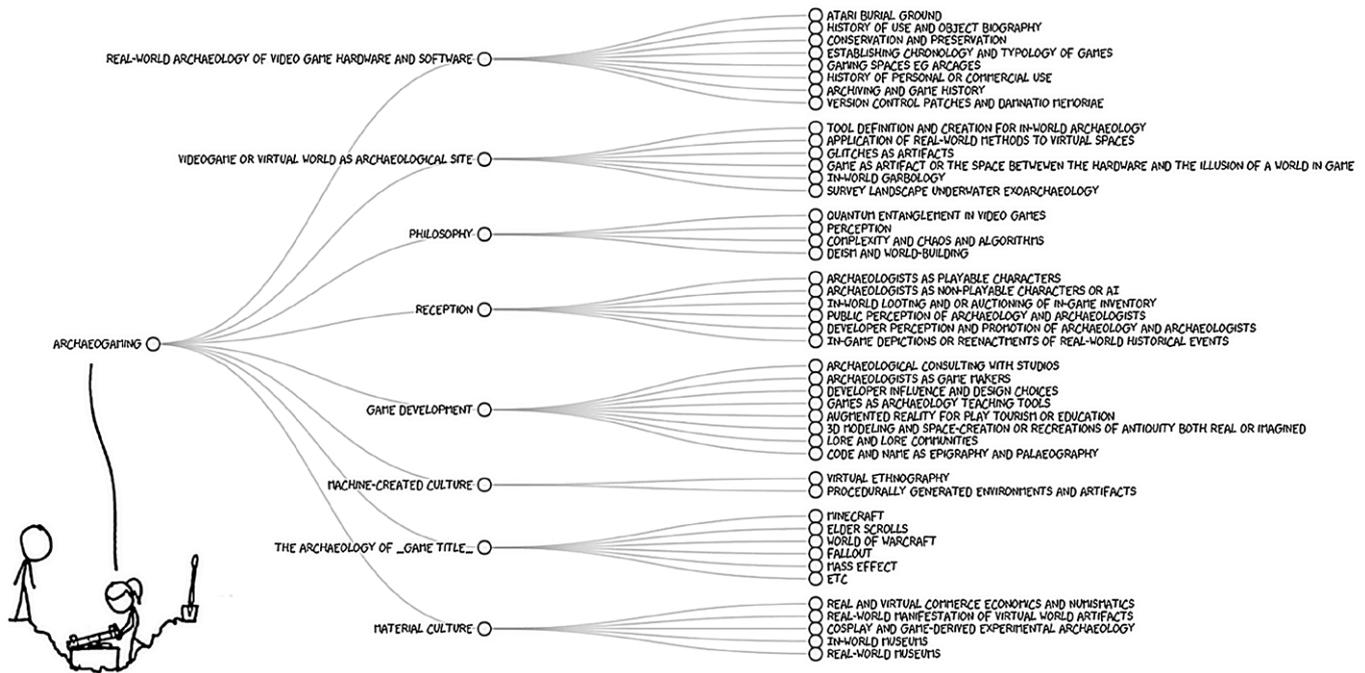
The spark of an enthusiastic, grassroots movement quickly kindled a small academic fire. Through blogposts, Twitter conversations, and the first (virtual or in-person) meetings, it became clear that there was a lot of work to do at the crossroads of video games and archaeology (Politopoulos *et al.* 2019, 166). This enthusiasm led to an ambitious potential breadth of the archaeogaming field, mapped by Reinhard and Graham (2016, figure 1).

Over the past 10 years, practitioners of archaeogaming have explored these early suggested routes. Reinhard has been primarily experimenting with the application of archaeological methods to the digital environment, as well as the contemporary archaeology of video game material and code. In 2014, he had already been involved in the first excavation of video games, the Atari burial ground excavation (Reinhard 2018, 22-29). For all the success the 1983 movie enjoyed, Atari's game *E.T.: the Extraterrestrial*, was a commercial flop and came to be known as the worst game ever. The company buried its failure quite literally, dumping millions of copies outside of Alamogordo, New Mexico. These copies were later excavated by Lightbox and Microsoft's Xbox, in collaboration with waste management experts and archaeologists. To date, the Atari Burial Ground excavation remains the only one of its kind.

In the strictly digital realm, Shawn Graham and others have explored Agent Based Modelling (ABM) approaches to study archaeology through games, *e.g.*, by using techniques from game design to make ABMs more playful or by quite literally asking players to play ABMs as a game (Graham 2017b; Rubio-Campillo *et al.* 2017). John Aycock, a computer scientist, has pioneered what he terms retrogame archaeology, a computational-meets-historical approach to study and reverse engineer early video games. In particular, he has investigated both the hardware and the software of old video games from obsolete consoles and early computers, to reconstruct game development and coding methods of the recent past (Aycock 2016, 2021; Aycock and Copplestone 2017; Aycock and Kroepfl 2021).

Another important research avenue of archaeogaming lies in the interactivity and storytelling potential of games. Video games are an inherently interactive medium that requires an active agent (player) to participate in the unfolding story. This makes games a unique medium among other media of popular culture. This strength has been leveraged from both an archaeological theory perspective and an outreach and didactics perspective. Tara Copplestone has highlighted that archaeological thinking and narratives have been shaped by materiality and linearity. In her research, she explored how the interactivity of games can create the developmental space for a multi-vocal, non-linear archaeology. She used Game platform Twine to do this, by applying it both directly in archaeological research, as well as within excavations and education

2 All presentations of the conference were recorded and can be found on VALUE's YouTube page on <https://youtu.be/XsVINdreW6E>.



DATA: ANDREW REINHARD / DESIGN & CODE: SHAWN GRAHAM (<https://gist.github.com/shawngraham/5a0366c0477dbae48891>) / IMAGE: RANDALL MUNROE (<http://xxcd.com/617/>) / ARCHAEOGAMING.COM / DEC. 18, 2015

Figure 1: The breadth of research coming out of archaeogaming (Reinhard and Graham 2016).

and outreach contexts (Copplestone and Perry 2016; Copplestone 2017; Copplestone and Dunne 2017).

The potential of games to expand the interpretative space of archaeology has also been highlighted by others. Florence Smith Nicholls, through academic publications, blogs, and journalistic work, has dealt with subaltern and alternate archaeologies, including archaeogaming and queer phenomenology, virtual dark tourism, video games and mapping, archaeogaming and photography, and more (Smith Nicholls 2018; 2021). While other disciplines, and game studies specifically, have dealt with similar issues, Smith Nicholls is the first one pioneering them in archaeology.

Along similar lines, ethics in archaeogaming and archaeological practice in games has been another core part of early archaeogaming. Meghan Dennis in particular has conducted extensive work on how archaeology is portrayed in and perceived through video games, as well as investigating the ethics of practice in digital heritage and archaeology (Dennis 2019; 2020; 2021). She has, for example, studied looting and its ethical repercussions in archaeological video games (Dennis 2016). Ethics has become a central theme in archaeogaming (see also *e.g.*, Flick *et al.* 2017) and has been an important stepping stone for ongoing

work on discussing and creating ethical frameworks for digital archaeology at large.

Finally, education and outreach are important aspects of archaeogaming, and the use of video games in teaching will be discussed below (see section 9.5). Even so, it is fair to say that education experts and historians had already carried out considerable work on that front. In the archaeogaming field, however, while some studies have been conducted (Koutsabasis *et al.* 2021), and archaeologists have been using video games in their teaching (Boom *et al.* 2020), little sustained and systematic research has been conducted on the potential and benefits of video games for archaeological and heritage education.

To summarize this overview of the history of archaeogaming, we can deduce a number of perceived aims and strengths of the field. As a grassroots, bottom-up initiative, it has the opportunity to develop outside of the strict confines of the academic ivory tower. This has meant both scientific and creative freedom, leading to popularly appealing, impactful, innovative projects and ideas. At the same time, its grassroots nature was crucial in sparking the inclusive and diverse field that is archaeogaming. Accessibility and ethics were not a development or additional part of research, but rather central and constitutive. Scholarly

voices otherwise marginalized in academia continue to force change and developments that, at least in our eyes, are not only positive, but also much needed.

In many other respects, the field of archaeogaming seemed to be at a trajectory of constant growth up until 2018. Major gaming outlets like Kotaku and the VICE Motherboard had featured archaeogaming projects (Caulderwood 2015; Plunket 2015). The SAA Archaeological Record (Morgan 2016) had paved the way for two major book publications, namely *Interactive Pasts* (Mol et al. 2017a) and the introductory book to archaeogaming (Reinhard 2018). Both became sources of inspiration for various other projects. The *ARISE* group (Arqueologia Interativa e Simulações Eletrônicas) was founded in Brazil, and every major archaeological conference (EAA, SAA, CAA) included one or even two well-attended sessions annually. The TIPC conferences included scholars from around the world, and there was a steady flow of publications in archaeological journals, as well as full archaeogaming classes and courses included in various Digital Archaeology programmes. This was an energetic moment in which it seemed like archaeogaming and its growing community were at the top of the (archaeological) world.

2.3 Archaeogaming in crisis

Here, we define ‘crisis’ not as being under existential threat, but rather in its original understanding of decision or inflection point (as in Greek *krisis*). For archaeogaming, such an inflection point came somewhere in 2019. Just a few years later, archaeogaming seems to have lost much of its momentum. As just one example of this crisis: many of the foundational blogs are currently inactive or have been taken offline, *Gingerygamer* and *Gamingarchaeo* being the prime examples. Andrew Reinhard has also passed the management and content creation of the *archaeogaming* blog to others, and the blog has become significantly less active, with only five posts in 2020 and four in 2021. Shawn Graham’s *ElectricArchaeo*, while still active, is less concerned with archaeogaming, and more with other aspects of digital humanities and digital archaeology. The Brazilian archaeogaming group *ARISE* has been cut off from its previous funding. Similarly, no major archaeogaming session has been held at annual conferences since the CAA conference in Krakow 2019 (an archaeogaming session was held at CAA 2023 after the submission of this paper).

This loss of momentum coincided partly with a global health crisis that restricted gatherings and movements and generally led to a reshuffling of (academic) priorities. Even so, one of the effects of this much more contained crisis has been that

scholars and other global citizens by necessity focused more on two aspects at the core of archaeogaming: having fun in digital spaces. Practically speaking, people were spending more time online and in digital environments, and especially gaming saw exponential growth (PWC 2022). In short, as with any other vibrant digital and playful undertaking during the pandemic, one would expect a (large) increase in activity, rather than the drawing down we saw with archaeogaming.

Twitter, for example, which has been instrumental in the development of the field of archaeogaming, witnessed a noticeable reduction in reach and engagement of the archaeogaming hashtag. The @archaeogaming Twitter account has also been largely inactive, in contrast to previous years, when it acted as a hub for information and news. Other pioneering profiles have also either been inactive or moved to different research interests. Even with a quick search of the hashtag on Twitter, one will see the same profiles tweeting about it over and over, with little to no discussion or other engagement with these tweets. At the same time, most of the tweets, about 80%, come from the US, the UK, or the Netherlands, showing the limited geographic scope of activity around this hashtag.

This is not to say that no new archaeogaming projects or groups have emerged in recent years. The *Games and Gaming Lab*, for example, was created at the University of Glasgow in 2019. This is a lab that focuses on interdisciplinary research in games and gaming, not only of video games but also tabletop, and across periods from ancient to modern. The *Archeogaming Con* (ArGaCon), an online convention on the topic of archaeology and video games, was also started in 2020 and returned in 2021. We have started the *Past-at-Play Lab* project – a citizen-science-based project in which both ancient and new games are played in an effort to understand the past and its role in the present. What all of these new initiatives have in common is that they are all separate initiatives, interesting and valuable, but weakly connected to each other and lacking core, shared scholarly tools and concepts.

Like most crises, the one in archaeogaming did not come out of thin air but resulted from developments that were part of its starting dynamics.³ In the following sections, we will evaluate how this has played out in three key respects.

3 For another critical perspective on the history, major players, and transitions in the archaeogaming field, see Hanussek 2019.

3 ARCHAEOLOGY AS A TOOL FOR STUDYING GAMES

Arguably, a major litmus test for archaeogaming is whether or not archaeology can be a useful tool for studying games, and vice versa. Reinhard has strongly argued in favour of this (2018), and various others have floated and developed ideas along these lines. An example from our own attempts of applying archaeological methods to study games was using a network approach to explore exchange practices and virtual material culture in massively multiplayer online games (Mol 2014a). Like much of the early archaeogaming scholarship, this research arose directly from the practice of gaming. Specifically from playing multiplayer online games while procrastinating on writing for a Ph.D. thesis combining network science and Caribbean Archaeology (Mol 2014b). The research itself consisted of first noticing and then observing in detail the pervasive and important role for virtual material culture in the creation of in-game social networks between game players – as a digital, direct analogy of the key role of material culture in archaeological social networks. The resulting paper argued that, conceptually, online games can be seen as Hobbesian ‘states of nature’ in which there is no social contract, with the key difference that in games, such a contract is not needed. Cooperation is inherent to some forms of play and further scaffolded by collaboratively questing for and sharing of in-game items and the resources needed to create them. The conclusion of the paper called for the recognition of (online) gaming spaces as testing grounds for archaeological (social) theory, a form of play-driven Agent-Based Modelling. This insight also arose independently in the works of others playing, making, and studying games (e.g., Graham 2020; McCall 2020). Even so, this strand of potential Game-Based-Modelling remains largely a call to action, with little to no practical work being done or shared afterwards.

Andrew Reinhard has gone beyond the application of specific archaeological methods in virtual playful environments, and considers video games to be archaeological sites in their own right (Reinhard 2018, 88). By combining several definitions of what constitutes an archaeological site (namely Hodder 2005; Holtorf 2005; LaMotta 2012), he argues that there is no inherent difference between digital and non-digital sites. Consequently, the tools that archaeologists use to study non-digital sites can also be used, relatively straightforwardly, to study digital sites (Reinhard 2018, 90). This is based on his understanding of a video game as an artefact existing in an installed

digital or physical space (e.g., a personal computer or a cartridge), the past of which exists in its code. He further considers these installation media an artefact and a potential archaeological site. Finally, he considers the activity of playing, what he terms ‘game-as-played’, and the digital space within the game is played and players interact, as a further archaeological site on which past activity can be recorded (Reinhard 2018, 91). These sites, in Reinhard’s opinion, can be explored by archaeologists through the analysis of media, through the analysis of files and structures, and through play. He attempted to showcase this approach to games as archaeological sites, as well as the validity of archaeological methods for the study of games, with the *No Man’s Sky Archaeological Survey* (NMSAS). *No Man’s Sky*, developed by Hello Games in 2016, is an online multiplayer exploration-survival game set in a procedurally generated galaxy. Planets are generated algorithmically, and include a random selection of biomes, materials, atmosphere, and (crucially for this research) ruins and languages of past civilizations. As a player you are dropped at a random location in the galaxy, and you travel towards the centre, while exploring the planets and collecting resources and material to upgrade your spaceship.

The NMSAS was designed to document this procedurally generated ‘culture’, the various planets and ruins of the galaxy. The survey was then opened to the archaeogaming community, as well as the Reddit community of *No Man’s Sky* players, for open participation. Participants had to agree to a code of ethics, designed by Cathrine Flick and Meghan Dennis, to secure an ethical approach to the data and to ensure the ethical behaviour of the members in the unknown universe.

As Reinhard recognized in his reflection, the project did not end up with the expected results (Reinhard 2018, 146). This partly had to do with the state of the game. *No Man’s Sky*, especially early on, under-delivered on its promises, the diversity of the galaxy’s planets was not as rich as expected, and gameplay was tedious. The disappointment at the game’s launch is well reflected in Reinhard’s writings. In addition to the underwhelming game experience, there were a number of objective issues that did not allow for explicit archaeological methods to be used, such as the lack of a coordinate system; the inability to dig, excavate, or lay out a grid; the impossibility of player communication; and more (Reinhard 2018, 144-5). Reinhard was very open about both the successes and the failures of his methods, publishing

all results and data open access – a testament to the robustness and seriousness of this archaeogaming scholarship. As the game was polished and more features were added, it became more viable for the NMSAS to approach some of its initial goals, particularly in documenting the remains of player bases in planets, and play as a group. There is great potential in this work. For example, it has contributed to understanding how online communities form, how people deal creatively with the challenges of digital places, and how games can change over time.

Still, in our opinion, the NMSAS survey is only marginally successful as an explicitly archaeological study of a game. At the heart of this, there lies an issue that goes beyond the lack of mechanics in one particular game. It rests in the suggestion that we can and should use existing archaeological theory and methods to study games because game artefacts and spaces are homologous to archaeology. More specifically, in the perspectives found in *Archaeogaming* (Reinhard 2018), video games are not only objects of archaeological study, but games themselves are in essence de facto archaeology. In practice, this leads to statements and examples that, when taken literally, are hard to fully underwrite from the perspective of either an archaeologist or a digital specialist. For example, there is the idea that as games are digital media that are stored, and also contain storage, they are not unlike the earth that contains, or ‘stores’, archaeological data (Reinhard 2018, 90). Anyone that has tried to upload their game save to the soil will disagree with this in a practical sense. From a more philosophical angle, the idea that all culture is binary data that can be stored and accessed accordingly goes against many of the insights of (post-processual) archaeology. Such practical and conceptual frictions are an inherent part of archaeogaming and need more and more in depth work to solve.

We underwrite the main tenet of archaeogaming (the movement) and *Archaeogaming* (the scholarly project by Reinhard): games are prime examples of digital things and places that need more and better study, and archaeology could help in this fun endeavour (Politopoulos *et al.* 2023). To sum up this section, despite a widely carried enthusiasm for such a project, there has been relatively little work done that explicitly connects to archaeological theory or methods and that is also sustainable or groundbreaking – for either archaeology as a discipline or the wider study of these digital media.

So, what could be a way forward for the study of games using archaeology? One way would be to embrace games as a playground for the future archaeology of digital things and places: let’s see which archaeological tools work and which break down, and why. This would require archaeogaming to fail gloriously, frequently and conspicuously, which is a fun and productive but risky academic proposition. A recent suggestion by Colleen Morgan is more helpful (Morgan 2021). She highlighted the crucial difference between digital things (in this case, objects in the video game *Minecraft*) and their real-life equivalent in the context of games. In her example, would the knowledge of, for example, analogue flint help us to understand *Minecraft* flint? And would that knowledge help us understand it in terms of archaeology? Morgan urges us to instead re-imagine an archaeology of digital things in connection to contemporary issues, such as through anti-fascism, decolonization, craft, degrowth, and prefiguration. We feel this would be a welcome move out of this particular crisis of archaeogaming, as it would excitingly require us to learn to handle or even invent new conceptual and methodological tools for digital, contemporary archaeology.

4 GAMES AS A TOOL FOR ARCHAEOLOGICAL OUTREACH

Outreach or science communication seems to be an obvious application of video games in archaeology. Video games are the largest entertainment medium and, given this popularity, it is not surprising that archaeologists see the potential in them for outreach projects. The perceived connection of games with a younger audience further reinforces this potential, and there have been several attempts to incorporate games in archaeological outreach (Koutsabasis *et al.* 2017). Much of the early research on video games and archaeology did, in fact, focus on the potential applications of games for virtual heritage (Champion 2011; 2015). The connection seems so self-evident that one would expect not only a *large* number of archaeogaming outreach projects, but also a relatively high success rate for such projects. The unfortunate reality is that, for reasons that we will explore, this enormous opportunity for outreach has also remained largely unrealized.

Our own first attempt at an archaeogaming outreach project was to stream video games on the popular online platform Twitch. Video content at large is a common and successful way of engaging gaming communities with particular topics such as history. There are several examples of popular history YouTube video series

from gaming channels, such as *Extra History* from the *Extra Credits* channel, which receive millions of views every year. Reaction videos on YouTube, where experts (archaeologists, historians, etc.) react to the content of specific historical video games, are also hugely popular, especially when coming from already established gaming channels like *IGN* and *Kotaku*.

We sought to harness this potential, albeit in a more interactive way. Live streaming differs from YouTube videos in that one is streaming games over live commentary, and can interact with a live audience via chat. We chose Twitch because it is the largest streaming platform in the world, with billions of watched hours annually. We started streaming in 2016 on our dedicated Twitch channel ([twitch.tv/streamingthepast](https://www.twitch.tv/streamingthepast)), with the ‘Streaming the Past’ series. In roughly 2-3-hour episodes, we picked a specific historical or archaeological theme, related it to a popular video game, and both analysed the depiction of the past in the game, and explored the particular topic. We used, for example, the game *Fallout 4* to discuss the collapse of societies, *Assassin’s Creed* to discuss the concept of historical agency, and *Far Cry: Primal* to discuss violence in human nature. Over the years, the series went from monthly episodes, to weekly, to eventually twice a week during the COVID-19 pandemic. This culminated in a Dutch Research Council-funded project in which we were livestreaming four to five days a week. These episodes were archived and many are available at VALUE’s YouTube channel (<https://youtube.com/c/VALUEfnd>).

Despite our continued work on Twitch, we have come to realize that this type of outreach and content production has many hurdles. First of all, as there was no other such archaeogaming project on Twitch, there were no other archaeologists we could turn to and ask how to combine archaeological scholarship and livestreaming. The second issue was that the discoverability of creators, how people originally find a channel, in the immense livestreaming landscape is extremely low. Neither Twitch nor YouTube algorithms actively support grassroots or low viewer count channels and, unless a channel has an established social media outreach, drawing in an audience is extremely difficult. Even if one has an audience, consistency in quantity and quality of output is key. Most professional (or at least highly viewed) streamers stream on an almost daily basis for several hours every day. As VALUE, we had neither the social media reach nor the required time to put into this streaming project. The result was that after five years

of streaming, our average streaming audience was around 10 individuals. Even when we acquired the sufficient gear for a high-quality production, stepped up our social media reach, and did the more regular two streams per week, we were unable to sustain a larger audience. The archives on YouTube also have a very low viewer count, usually under 100 views, and most successful videos have just over 1,000 views.

A key issue with such projects or events is that individuals and institutions are often unaware that using games for outreach is not like waving a magic wand. It is not uncommon to see universities use video games as a way of reaching out to prospective students, and we have done this for Leiden University. We also have other stories of archaeogaming colleagues whose work has been used for marketing purposes (website or Twitter headlines), introduction days, so-called experience days at universities, and more. To use gaming lingo, video games increase the ‘coolness’ factor of an institution, particularly in the eyes of students. However, universities tend to make use of archaeogaming for branding purposes rather than actually seeking to support it. At the same time, the amount of work required for projects like *Streaming the Past*, or other outreach projects, is hugely undervalued within academia.

When one puts in the necessary infrastructure and time, however, archaeogaming outreach projects can be rather successful, such as our *RoMeincraft* projects. As VALUE Foundation in 2017 we were able to obtain funding from the South Holland province to develop a gaming outreach project to raise awareness of Dutch Roman heritage and the Dutch Limes in particular. The project was initially designed specifically for South Holland, in a series of 10 events, during which visitors and participants would reconstruct the forts of the Roman border in the Netherlands in the popular video game *Minecraft*.

This first version was quite successful, with more than 1,000 participants and considerable local impact (Politopoulos *et al.* 2019). Other Dutch provinces asked us to replicate it, and we even crossed the border to host events in Belgium in 2019. We also collaborated with other organizations such as the Prince Claus Fund and the National Museum of Antiquities to develop similar *Minecraft* reconstruction projects. In 2019, we provided advisory and technical support for *MineRhonda*, a similar project developed by DigVentures and the Valley Kids as part of a larger Welsh heritage project, *Unloved Heritage?* (<https://unlovedheritage.wales/>).

We continue with various Minecraft projects today, and we now have several thousand participants from the Netherlands and elsewhere, with dozens of reconstructed heritage sites. The success of our Minecraft projects stems not just from their creative approach, but also from the fact that we could invest the necessary time and funds to develop them. And while we succeeded in obtaining the funds to realize them, the issue of time remained. We were able to do these projects only in our spare time, working evenings and running events on weekends or other days off. *RoMeincraft* might be our most successful outreach project, but in its current form, it is not sustainable.

5 GAMES AND THE PAST AS A TOOL FOR BUILDING BRIDGES

One particular aim to which archaeogaming seems very suited is for building bridges between (sub) disciplines with which archaeology has traditionally had few collaborations. One such connection seems very straightforward: archaeology of and in games can make connections with game studies. Game studies coalesced in the early nineties when scholars in literature, media studies, philosophy, and computer sciences took a specific interest in the then still relatively new phenomenon of video games (Aarseth 2001). Media archaeology is another field, itself overlapping with game studies, with apparent potential for cross-discipline interactions. Beyond this, the potential of games for learning about the past could garner collaborations with education studies and museology.

Moreover, archaeogaming is not the only field that deals with video games and the past. Historians, for example, have also extensively engaged with video games and the representation of history. Adam Chapman, who has done pioneering work on this topic (Chapman 2016), recently collaborated with three other people to develop the Historical Games Network (HGN), a hub that aims to bring together academic, game developers, and cultural workers to explore the connections between history and games. Topics of exploration that have emerged from activities of the network include historical truth, ethics, (post-) colonialism, and education. Other initiatives exploring the connection between history and games include sessions organized at the *Clash of Realities* conference (Lorber and Zimmermann 2020), *The Middle Ages in Modern Games* conference series organized by Robert Houghton (2020), and the German *Gespielt*, which is interested in historical work with digital games (Gespielt 2016).

There has also been significant research into the use of games for teaching history (e.g., Giere 2019; Lawler and Smith 2021; Worthington 2018). Extensive studies have been done on the benefits of games for learning, their effective use in the classroom, and informal learning through games (e.g., Ferdig 2008; Kafai and Burke 2016; Klopfer *et al.* 2018). When it comes to the teaching of history, however, the work of Jeremiah McCall has been seminal (2011). McCall, who teaches history in secondary education in the US, has focused on the use of games in the classroom (McCall 2012a; 2012b), broader themes and practices for the use of games in historical education (2016), and classification and definition of historical games and their trends (2020).

It becomes evident, then, that there is extensive interest in the topic, not only from archaeologists, but also in many other disciplines that concern themselves with the study of the past. Yet this potential is not being realized in practice. The most obvious example of this is the analogous track of historical game studies and archaeogaming. Each subfield is vanishingly small, consisting of a very small number of scholars who actually get paid for doing sustained work in this field – to our estimation, you can count them on the fingers of your hands. This is not an indictment of the high-quality, avocational (or otherwise not financially compensated) scholarship done, but a gauge of how sustainable these subfields are as academic professions. Moreover, any outsider looking at these academic niches would think they coincide seamlessly: both subfields are preoccupied with the past and digital games. Yet in practice we have one field studying video games as archaeology, archaeogaming, while the other, historical game studies is studying video games as history. As a result, the founding texts for these two subfields, *Archaeogaming* (Reinhard 2018) and *Digital Games as History* (Chapman 2016), were written emphatically from within their disciplines looking outward at games. We are also guilty of this: we have published the vast majority of our papers in archaeology and heritage studies journals and books, like this one.

VALUE has worked since its inception as a multi-disciplinary collective of archaeologists, heritage and museum scholars, and, indeed, historians, organizing conferences, workshops, edited volumes, papers, internships, web platforms, and more for these same groups and beyond. So we know from experience that any deeper separation between archaeogaming and historical game studies is purely academic. Beyond VALUE, one hopeful sign is that in the past year, we

have seen more interactions in online panels and more informal gatherings, such as those organized by the Historical Game Studies network. Indeed, one potential path forward could be to collectively abandon the archaeogaming ship and continue the same activities under the banner of historical game studies. Then again, the study of the past (in games) is much wider than history and its aims for study. Indeed, archaeogaming has forged ahead in valuable aspects in which historical game studies has not yet seen much work, such as audience-focused, ethics-led, data-driven, and code-based studies of games (Aycock 2021; Dennis 2020; Mol *et al.* 2016; Politopoulos *et al.* 2019; Reinhard 2018).

Our solution is simple: why not attain the best of both of these (and more) worlds through truly interdisciplinary work? This takes some boundary work but is not that hard in practice. In our activities as VALUE, we have opted to use concepts around which we can build bridges, such as the idea of ‘interactive pasts’, focusing on a core aspect of games, their interactivity, and how they bring this to our understanding and valuation of our collective past. Coalescing around the concept of play (or even fun) and the past could also provide richer ground for interdisciplinary work. This particular focus has the benefit that we can look for collaborations with those who study play more broadly, beyond digital games and beyond play in the digital present (for an expanded version of this argument, see Politopoulos *et al.* 2023).

This academic joint venture is important and necessary because we should be able to use it as a bridge-building tool for making concrete contributions to the field of game development. Indeed, one area in which both archaeogaming and historical game studies have been very effective is showing *how* the game industry draws on the past for narrative, aesthetic, and even game mechanical purposes. As specialists who understand the past and how it works in the present, we find that it is quite possible, sometimes even (too) easy, to present fundamental critiques of game design choices made and the specific historical and heritage experiences to which they lead. It is troubling, for example, that the majority of the most popular games provide experiences of the past that are monolithic and narrow in their understanding of historical processes and cultures. Arguing for this based on scholarly evidence is one thing; it is much harder to effect any change. We know this, as it has also been a core experience of our own scholarly practice.

The long-running 4X strategy game *Sid Meier’s Civilization*, in which you lead a civilization from the

Stone to the Space Age, has proved to be a particularly fruitful target for our critiques (Mol *et al.* 2017b). In our ‘One More Turn’ series, recorded live on Twitch and archived on YouTube, we had a blast meticulously and continuously ‘unmasking’ this game’s particular and deeply ideological view on how civilization works – driven by technology, singular leaders, specific cultural traits, and hegemonic and colonialist power structures. With this, we followed in a scholarly tradition that is almost as old as the 30-year-old game itself.

In fact, in his recent memoirs, in a chapter dedicated completely to academic criticism, Sid Meier even jokingly refers to his critics as ‘people with too much time on their hands’ (Meier 2020, 229). He explains to his readers that this critical scholarship only shows how much these critics care. Even so, as becomes clear from this chapter, the rest of the memoir, and the conservative nature of this popular game series, the collective might of the critical scholarly pen could not and will not be able to move Sid Meier and his *Civilization* towards change. Indeed, why would he? *Sid Meier’s Civilization* series is a giant of the gaming industry and has been so for 30 years. The point is: game developers, especially the biggest companies in the space, can negate any and all scholarly critiques, justified or not, and will still, generally, remain successful in all the ways that matter most to the game industry – as something fun, as a commercial product, as game journalists’ critical darling, and as ‘accidentally’ societally impactful.

This does not mean we should take no action. We firmly believe that the insights of archaeogaming and other scholarship at the intersection of the past and play can help citizens engage with the past through games. We are particularly optimistic because of collaborations with the field and so-called indie studios, smaller teams of game developers that have both the operational, artistic, and intellectual flexibility to work with scholarly input. Yet indie studios are frequently in precarious situations as businesses: when a small group of people is working on a costly and highly complex project like a commercially viable game, all their time needs to be well spent. So, to cross this particular bridge and engage in open communication that is of value to both sides, scholar and game developer, archaeogaming must come with a solid toolset at our disposal. This is perhaps the best reason for building bridges academically: we quite simply cannot afford to take academic disciplinary ‘boundary games’ into our collaborations with the gaming industry.

6 CRITICAL MISSES, GLORIOUS FAILURES, AND CONTINUING THE FUN

To sum up, after outlining the aims and trajectory of archaeogaming – a movement born in and out of the fun global citizens have with the past in the contemporary digital playground of video games – we provided three key vectors for our critique:

1. the study of video games using archaeological tools and the use of video games as tools for archaeological research have not moved much beyond their conceptual phase, or in cases where they have, they have not yet produced a clear argument for how archaeological tools can consistently and structurally be of added value for the larger scholarly understanding of games.
2. the outreach power of video games remains largely unharnessed, as outreach archaeogaming projects are not being institutionally supported, while universities are using outreach through video games as a gimmick rather than valuing it as a promising science communication strategy.
3. the interdisciplinary potential of archaeogaming is not being realized because overarching disciplinary silos and practices have a constraining effect on a potentially much wider scientific and societal debate around the (re-)creation and experience of the past in games.

We could uncharitably refer to these critiques as critical misses – a roleplaying game term for an unexpected failure, resulting from rolling a 1 on a die. The failings we discussed are unexpected because they occur in areas where archaeogaming was arguably very strongly positioned. As we outlined, in our opinion, these strengths turned out to be exactly those places where archaeogaming is lagging. What may have happened is that we did not see that the tools it offered for new digital research, outreach, and interdisciplinary scholarship were much more slippery than we had anticipated in our and others' early excitement around archaeogaming.

The result of this is that the current state of archaeogaming is analogous to 'shareware', an unsustainable game business model from the 90s. Developers would distribute sizable demos of their products to potential customers for free, sometimes containing almost a third of the entire game. People had a lot of fun playing these freebies and shared them widely, but only a fraction of players would ever end up paying for (and playing) the actual full game.

Archaeogaming is academic shareware because it has certainly made the rounds and many played around with it for a bit, yet few people go in for the full deal. What is more, even those who most actively engage with archaeogaming – those who develop research, tweet, create projects, streams, and videos – are doing it mostly, if not exclusively, on their own time, without stable sources of compensation or recognition for the effort involved in their trailblazing efforts.

Indeed, many of our colleagues who have moved away from archaeogaming have done so because it does not offer a sustainable academic trajectory. There are very few Ph.D. and even fewer postdoc positions out there – and good luck being hired in an archaeogaming tenure-track position. One can expect to work within a digital archaeology or digital heritage framework, in which games could be used, but they would not then be the primary focus. The reality is that many archaeogaming scholars have had so much fun exploring and sharing this new digital playground that we forgot to mention that there is a price tag attached. Reinhard has argued that archaeogaming still has 'far to go in justifying its existence not only to the academy and to more traditional archaeologist colleagues but also to the general public' (Reinhard 2018, 9), but yet has also already positioned it as a fully-fledged subdiscipline of archaeology.

This seems like a bit of double play: archaeogaming cannot both already have arrived and yet still need significant foundational work. This approach thus reminds us of another, more recent game business strategy: the 'early access' game (Horn 2019). An early access game is a game that is still in development but already available to consumers. It is there to be played, even if not all the game mechanics and assets are present or working. Going into early access can be a great strategy for obtaining resources while still designing, but it also runs the risk that people will play the game and reject it for its flaws or get bored of it before it is a finished product. As we have convincingly argued above, archaeogaming is only in the very early stages of development, and there is a significant chance that it may never leave this phase if some of the current critical misses are not followed up by some solid updates.

At the moment, archaeogaming is thus both unpaid, fun shareware and an early access serious academic discipline; a risky, interstitial position to be in. So, how does archaeogaming get out of the double bind in which it finds itself? We feel the best opportunity to move forward is to continue to embrace the open, diverse,

accessible, and fun-fuelled scholarly practices that have been the defining assets of early archaeogaming, and not be afraid to leave behind more traditional academic tools of the trade. This means that, as a scholarly movement, we should not focus too much on what academic practice and established (digital) theory and method tell us archaeogaming should do to be successful. We should reimagine archaeogaming as a grassroots, even activist movement that will reshape our understanding of the present digital past (Morgan 2021), reinvigorate its fieldwork-driven experiments and interdisciplinary endeavours (Aycok and Copplestone 2017; Reinhard 2018, 88-161), and invest more in forging reciprocal relations with the gaming industry (Mol *et al.* 2017a) and playful citizens (Politopoulos *et al.* 2019). At its core, archaeogaming is about collectively making, exploring, and playing in this wild, new digital playground.

Play is messy and almost any research or outreach project we have been part of has failed in minor (or sometimes major) ways. Instead of focusing on the successes and academic potential of archaeogaming, it should remain a movement in which tools and their users can fail gloriously (Graham 2019, 129). If games have taught us anything, it is that failing is not fun, but failing gloriously is. We should thus use failure as potential for change, and commit to discuss it with an attentive and caring stance, in an effort to be our own and others' critical friends. As we have shown with our critique, archaeogaming has all the tools to fail gloriously, and turn the next roll of the dice into a solid hit.

REFERENCES

- Aarseth, E. 2001. "Computer game studies, year one." *Game Studies* 1(1).
- Aycok, J. 2016. *Retrogame Archeology: Exploring Old Computer Games*. New York: Springer.
- Aycok, J. 2021. "The Coming Tsunami of Digital Artefacts." *Antiquity* 95(384), 1584-1589. DOI:10.15184/aqy.2021.84.
- Aycok, J., and T. Copplestone. 2017. "Entombed: An Archaeological Examination of an Atari 2600 Game." *arXiv preprint arXiv:1811.02035*.
- Aycok, J. and H. Kroepfl. 2021. "The Desolation of Vixens." In *Return to the Interactive Past: The Interplay of Video Games and Histories*, edited by Csilla E. Ariese, Bram van den Hout, Krijn H.J. Boom, Angus A.A. Mol and Aris Politopoulos, 45-56. Leiden: Sidestone.
- Bogost, I. 2016. *Play Anything: The Pleasure of Limits, the Uses of Boredom, and the Secret of Games*. New York: Basic Books.
- Boom, K.H., C. Ariese, B. van den Hout, A.A.A. Mol and A. Politopoulos. 2020. "Teaching Through Play: Using Video Games as a Platform to Teach about the Past. In *Communicating the past in the digital age. Proceedings of the international conference on digital methods in teaching and learning in archaeology (12th-13th October 2018)*, edited by Sebastian Hageneuer, 27-44. London: Ubiquity Press. DOI:10.5334/bch.c.
- Caulderwood, K. 2015. "The Archaeologist Who Studies 'World of Warcraft'." August 13 2015 <https://www.vice.com/en/article/pgang9/the-archaeologist-who-studies-world-of-warcraft>.
- Chapman, A. 2016. *Digital Games as History: How Videogames Represent the Past and Offer Access to Historical Practice*. London and New York: Routledge.
- Champion, E. 2011. *Playing with the Past*. London: Springer. DOI:10.1007/978-1-84996-501-9_6.
- Champion, E. 2015. *Critical Gaming: Interactive History and Virtual Heritage*. London and New York: Ashgate Publishing Limited. DOI:10.4324/9781315574981.
- Copplestone, T.J. 2014. *Playing with the Past: The Potentials and Pitfalls of Video Games for and about Cultural Heritage*. MA thesis, University of York.
- Copplestone, T.J. 2017. "Designing and Developing a Playful Past in Video Games." In *The Interactive Past: Archaeology, Heritage, and Videogames*, edited by Angus A.A. Mol, Csilla E. Ariese-Vandemeulebroucke, Krijn H.J. Boom and Aris Politopoulos, 85-97. Leiden: Sidestone.
- Copplestone, T.J. and L. Botham. 2014. "Buried. An Ergodic Literature Game." Accessed 12 January 2022 <http://www.heritagejam.org/exhibition/2014/7/11/buried-an-ergodic-literature-game-tara-copplestone-and-luke-botham>.
- Copplestone, T.J. and D. Dunne. 2017. "Digital Media, Creativity, Narrative Structure and Heritage." *Internet Archaeology* 44. DOI:10.11141/ia.44.2.
- Copplestone, T.J. and S. Perry. 2016. "The Heritage Jam." *Archaeology Scotland* 25(2), 12-13.
- Dennis, M.L. 2016. "Archaeogaming, Ethics, and Participatory Standards." *SAA Archaeological Record* 16(5), 29-33.
- Dennis, M.L. 2019. *Archaeological Ethics, Video Games, and Digital Archaeology: A Qualitative Study on Impacts and Intersections*. PhD diss. University of York.

- Dennis, M.L. 2020. "Digital Archaeological Ethics: Successes and Failures in Disciplinary Attention." *Journal of Computer Applications in Archaeology* 3(1), 210-218. DOI:10.5334/jcaa.24
- Dennis, M.L. 2021. "Getting it Right and Getting it Wrong in Digital Archaeological Ethics." In *Virtual Heritage: A Guide*, edited by Erik Champion, 105-113. London: Uniquity Press. DOI:10.5334/bck.j
- Ferdig, R.E. 2008. *The Handbook of Research on Effective Electronic Gaming in Education*. Hershey-New York: Information Science Reference. DOI: 10.4018/978-1-59904-808-6
- Flick, C., M.L. Dennis, and A. Reinhard. 2017. "No Man's Sky Archaeological Survey Code of Ethics." Archaeogaming accessed 12 January 2022 <https://archaeogaming.com/2016/07/15/no-mans-sky-archaeological-survey-code-of-ethics/>
- Gardner, A. 2007a. "Playing with the Past. A Review of Three 'Archaeological' PC Games." *European Journal of Archaeology* 10(1), 74-77.
- Gardner, A. 2007b. "The Past as Playground: The Ancient World in Video Game Representation." In *Archaeology and the Media*, edited by Timothy Clack and Marcus Brittain 255-272. California: Left Coast Press.
- Gespielt. 2016. "Manifest für geschichtswissenschaftliches Arbeiten mit Digitalen Spielen!" Accessed 11 January 2022 https://gespielt.hypotheses.org/manifest_v1-1.
- Graham, S. 2012. "HIST3812 games & simulation for Historians. A tentative course schedule & outline." Accessed 12 January 2022 <https://electricarchaeology.ca/2012/11/09/hist3812-a-tentative-course-schedule-outline/>.
- Graham, S. 2013. "Why I Play Games." Accessed 12 January 2022 <https://electricarchaeology.ca/2013/01/10/why-i-play-games/>.
- Graham, S. 2015. "Field Notes from a Virtual Unconference." Accessed 12 January <https://electricarchaeology.ca/2015/06/01/field-notes-from-a-virtual-unconference/>.
- Graham, S. 2017a. "Archaeogaming2 Unconference – Take 2." Accessed 12 January <https://electricarchaeology.ca/2017/03/07/archaeogaming2-unconference-take-2/>.
- Graham, S. 2017b. "On Games that Play Themselves: Agent Based Models, Archaeogaming and the Useful Deaths of Digital Romans. In *The Interactive Past: Archaeology, Heritage, and Videogames*, edited by Angus A.A. Mol, Csilla E. Ariese-Vandemeulebroucke, Krijn H.J. Boom and Aris Politopoulos, 123-13. Leiden: Sidestone.
- Graham, S. 2019. *Failing Gloriously and Other Essays*. North Dakota: AbeBooks. DOI:10.31356/dpb015.
- Graham, S. 2020. *An Enchantment of Digital Archaeology. Raising the Dead with Agent-Based Models, Archaeogaming and Artificial Intelligence*. New York: Berghahn Books. DOI: 10.3167/gra7866.
- Hodder, I. 2005. "Reflexive Methods." In *Handbook of Archaeological Methods*, edited by Herbert D.G. Maschner and Christopher Chippindale 643-672. Lanham MD: AtlaMira Press.
- Holtorf, C. 2005. *From Stonehenge to Las Vegas. Archaeology as Pop Culture*. Lanham, MD: AltaMira Press.
- Houghton, R. 2020. *The Middle Ages in Modern Games. Conference Proceedings Vol. 1*. Winchester: The Public Medievalist.
- Horn, C. 2019. "Andrew Reinhard. Archaeogaming: An Introduction to Archaeology in and of Video Games." *European Journal of Archaeology* 22(4), 612-616.
- Hanussek, B. 2019. "Conducting Archaeogaming and Protecting Digital Heritage. Does the Future for Archaeology Lie in the Immaterial." *Arts et Sciences* 3(1), 1-15.
- Hussey, D.R. 2013. "Reading into the Cold War in Video Games." Accessed 12 January 2022 <https://www.playthepast.org/?p=4101>.
- Kafai, Y.B. and Q. Burke. 2016. *Connected Gaming: What Making Video Games Can Teach Us about Learning and Literacy*. Cambridge MA: MIT Press.
- Kee, K., S. Graham, P. Dunae, J. Lutz, A. Large, M. Blondeau, and M. Clare. 2009. "Towards a Theory of Good History Through Gaming." *Canadian Historical Review* 90, no. 2, 303-326. DOI:10.3138/chr.90.2.303.
- Klopfer, E., J. Haas, S. Osterweil, and L. Rosenheck. 2018 *Resonant Games: Design Principles for Learning Games that Connect Hearts, Minds, and the Everyday*. Cambridge MA: MIT Press. DOI:10.7551/mitpress/10887.001.0001.
- Koutsabasis, P. 2017. "Empirical Evaluations of Interactive Systems in Cultural Heritage: A Review." *International Journal of Computational Methods in Heritage Science* 1(1), 100-122. DOI:10.4018/IJCMHS.2017010107.
- Koutsabasis, P., A. Gardeli, K. Partheniadis, P. Vogiatzidakis, V. Nikolakopoulou, P. Chatzigrigoriou, and S. Vosinakis. 2021. "Field Playtesting with Experts' Constructive Interaction: An Evaluation Method for Mobile Games for Cultural Heritage."

- In *2021 IEEE Conference on Games (CoG)*, pp. 1-9. DOI:10.1109/CoG52621.2021.9619049.
- LaMotta, V. 2012. "Behavioural Archaeology." In *Archaeological Theory Today*, edited by I. Hodder, 62-92. Cambridge: Blackwell.
- Lawler, J. and S. Smith. 2021. "Gaming the Past: Video Games and Historical Literacy in the College Classroom." In *Return to the Interactive Past: The Interplay of Video Games and Histories*, edited by Csilla E. Ariese, Bram van den Hout, Krijn H.J. Boom, Angus A.A. Mol and Aris Politopoulos 173-188. Leiden: Sidestone.
- Lorber, M. and F. Zimmermann eds. 2020. *History in Games: Contingencies of an Authentic Past*. Berlin: transcript Verlag. DOI:10.14361/9783839454206.
- McCall, J. 2011. *Gaming the Past: Using Video Games to Teach Secondary History*. London and New York: Routledge. DOI:10.4324/9781003272229.
- McCall, J. 2012a. "Historical Simulations as Problem Spaces: Criticism and Classroom Use." *Journal of Digital Humanities* 1(2), 1-2.
- McCall, J. 2012b. "Navigating the Problem Space: The Medium of Simulation Games in the Teaching of History." *The History Teacher* 46(1), 9-28.
- McCall, J. 2016. "Teaching History with Digital Historical Games: An Introduction to the Field and Best Practices." *Simulation & Gaming* 47(4), 517-542. DOI:10.1177/1046878116646693.
- McCall, J. 2020. "The Historical Problem Space Framework: Games as a Historical Medium." *Game Studies* 20(3).
- Meier, S. 2020. *Sid Meier's Memoir! A Life in Computer Games*. New York: WW Norton.
- Giere D. 2019. *Computerspiele – Medienbildung – historisches Lernen: Zur Repräsentation von Geschichte in Digitalen Spielen*. Frankfurt: Wochenschau Verlag.
- Mol, A.A.A. 2014a. "Play-things and the Origins of Online Networks: Virtual Material Culture in Multiplayer Games." *Archaeological Review from Cambridge* 14(1), 144-166.
- Mol, A.A.A. 2014b. *The Connected Caribbean: A Socio-Material Network Approach to Patterns of Homogeneity and Diversity in the Pre-colonial Period*. Leiden: Sidestone.
- Mol, A.A.A., C.E. Ariese-Vandemeulebroucke, K.H.J. Boom, A. Politopoulos and V. Vandemeulebroucke. 2016. "Video Games in Archaeology: Enjoyable but Trivial?" *SAA Archaeological Record* 16(5), 11-15.
- Mol, A.A.A., C.E. Ariese-Vandemeulebroucke, K.H.J. Boom and A. Politopoulos eds. 2017a. *The Interactive Past: Archaeology, Heritage, and Video Games*. Leiden: Sidestone.
- Mol, A.A.A., A. Politopoulos and C.E. Ariese-Vandemeulebroucke. 2017b. "From the Stone Age to the Information Age: History and Heritage in Sid Meier's Civilization VI." *Advances in Archaeological Practice* 5(2), 214-219. DOI:10.1017/aap.2017.9.
- Morgan, C. 2009. "Re-building Çatalhöyük: Changing Virtual Reality in Archaeology." *Archaeologies: Journal of the World Archaeological Congress* 5(3), 468-487. DOI:10.1007/s11759-009-9113-0.
- Morgan, C. ed. 2016. "Video games and archaeology." *SAA Archaeological Record* 16(5).
- Morgan, C. 2021. "An Archaeology of Digital Things. Social, Political, Polemical." *Antiquity* 95(384), 1590-1593. DOI:10.15184/aqy.2021.125.
- Plunket, L. 2015. "Actual Archaeologist is Digging Through World of Warcraft, Skyrim." Accessed 12 January 2022 <https://kotaku.com/actual-archaeologist-is-digging-through-world-of-warcraft-1724001740>.
- Politopoulos, A. 2014a. "Mirroring Gods in Theros: Conquering Mythological Stereotypes in Magic the Gathering." Accessed 12 January 2022 <https://www.playthepast.org/?p=4570>.
- Politopoulos, A. 2014b. "Video Games and Archaeology. An Unlikely Match?" Accessed 12 January 2022 <https://youtu.be/6mi5lw1HWzE>.
- Politopoulos, A, C.E. Ariese, K.J.H. Boom and A.A.A. Mol. 2019. "Romans and Rollercoasters: Scholarship in the Digital Playground." *Journal of Computer Applications in Archaeology* 2(1), 163-175.
- Politopoulos, A. and A.A.A. Mol. 2021. "Video Games as Concepts and Experiences of the Past." In *Virtual Heritage: A Guide*, edited by Erik Champion, 81-92. London: Uniquity Press. DOI:10.5334/bck.h.
- Politopoulos, A., A.A.A. Mol and S. Lammes. 2023. "Finding the Fun: Towards a Playful Archaeology." *Archaeological Dialogues* 30(1).
- PWC. 2022. "Perspectives from the Global Entertainment & Media Outlook 2022-2026: Fault Lines and Fractures: Innovation and Growth in a New Competitive Landscape." Accessed 17 April 2023 <https://www.pwc.com/gx/en/industries/tmt/media/outlook/outlook-perspectives.html>.
- Reinhard, A. 2013. "What is Archaeogaming." 9 June 2013 <https://archaeogaming.com/2013/06/09/what-is-archaeogaming/>.
- Reinhard, A. 2018. *Archaeogaming: An Introduction to Archaeology in and of Video Games*. New York: Berghahn Books.

- Reinhard, A. and S. Graham 2016. "Archaeogaming map (revised)." Accessed 11 January 2022 <https://archaeogaming.com/2015/12/18/archaeogaming-map-revised/>.
- Rubio-Campillo, X., J. Caro Saiz, G.H. Pongiluppi, G. Laborda Cabo, and D. Ramos Garcia. 2017. "Explaining Archaeological Research with Videogames: The Case of Evolving Planet." In *The Interactive Past: Archaeology, Heritage, and Videogames*, edited by Angus A.A. Mol, Csilla E. Ariese-Vandemeulebroucke, Krijn H.J. Boom and Aris Politopoulos, 153-165. Leiden: Sidestone.
- Smith Nicholls, F. 2018. "Virtual Dark Tourism in The Town of Light." In *The Phenomenology of Real and Virtual Places*, edited by Erik Champion, 223-237. New York: Routledge.
- Smith Nicholls, F. 2021. "Fork in the Road: Consuming and Producing Video Game Cartographies." In *Return to the Interactive Past: The Interplay of Video Games and Histories*, edited by Csilla E. Ariese, Bram van den Hout, Krijn H.J. Boom, Angus A.A. Mol and Aris Politopoulos 117-134. Leiden: Sidestone.
- Travis, R. 2011. "Convict Socrates! Save Civilization! Learn Ancient Greek! Take Operation MENIS, Coming this Summer!" Accessed 12 January 2022 <https://www.playthepast.org/?p=1015>.
- Worthington, T.A. 2018. "Letting Students Control their own Learning: Using Games, Role-plays, and Simulations in Middle School U.S. History Classrooms." *The Social Studies* 109, 136-50

Reflections

Rachel Opitz

What enables and motivates us, as digital archaeologists, to continue to pursue work we characterise as somehow limited, somewhat unsatisfying, and only ever partially reaching its full potential? The answer to this question, which underlies the reflections gathered in this volume, may lie in the responses given by Lambers's students when asked why they chose to pursue a specialisation in digital archaeology. These students reported a sincere desire to involve themselves in a future-oriented and impactful community, while pragmatically acknowledging that if they don't stay in archaeology the transferrable digital skills gained will help them to land a job elsewhere (Lambers, this volume). The balance of pragmatism and optimism expressed by these students suggests that from the outset people interested in digital archaeology have little innocence about the challenging realities of this kind of work. Having this "loss of innocence in our origin" (Haraway 1985, 158) may be what creates a space for work shaped by repeated encounters between techno-optimism and less-than-sunny realities.

The tensions integral to work in this space are reflected in the position set out by Kalaycı and Hacıgüzeller, for whom the digital transformation of archaeological and heritage practice is tremendously valuable, yet deeply unsatisfying. Their contribution sets out the questions which sit at the core of this volume in stark relief: What are our motivations when we use digital technologies in our work? What are the real impacts of incorporating digital tools and methods into archaeological working practices? And why do the benefits of 'going digital' never seem to quite match our hopes and expectations?

Their chapter proposes two responses to these questions, which provide a framework which connects the specific discussions found in the subsequent chapters. First, they make the case that the myths and metaphors the digital community uses to talk about digital phenomena are obviously and intentionally fictions, but, like other powerful stories, it's easy to forget, just for a moment, that they aren't real. Through the process of repeatedly using metaphors in our daily work and conversations, we unconsciously elide the imagery, ideas and stories we use to describe technological systems with our actual conceptualisation of those systems. Because the power, beauty, speed, strength, grace and greatness integral to an effective (affective) myth can't be lived up to by mere reality, we are inevitably set up for disappointment when encountering the realities described by the stories. Second, and more seriously, they suggest that even if we told more modest stories about what digital transformations could do for our practice, the socio-technical systems of late-stage capitalism in which we (contemporary Western society) are operating would make meaningful success and satisfaction unachievable because we can't get away from the exploitation of labour, reinforcement of inequalities, and drive for constant growth and innovation which are integral to our current operational context. Critical discussions of the societal context which shapes contemporary archaeological and heritage practice and the impacts of overwork,

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labour injustices, social and economic inequalities, excessive pressure to innovate, and related malaises regularly note the role of our engagements with digital technologies and data (Caraher 2019; Cobb and Crellin 2022; Cook 2019; Dennis 2020; Flexner 2020; Fredheim 2020; Huggett *et al.* 2018; Huggett 2019; Morgan 2021; Perry *et al.* 2018; Richardson 2018; Wright and Richards 2018; Zorzini 2021). Reading across the articles cited above, the party line is that while the digital transformation has led to real progress in placing Objectivity, Transparency, Inclusivity and Decentralization centrally in the discourse on good archaeological and heritage practice, our ability to fulfil these promises remains constrained by our wider societal context.

To move beyond the limitations imposed by late-stage capitalism, Kalaycı and Hacıgüzeller call for, “an explicit and well-developed social theory of the digital” which addresses the role of labour in digital systems, treats inequalities in access to the digital as a human rights issue, and is formally and explicitly anti-Silicon Valley (implicitly construed as a paragon of late-stage capitalism). This call clearly expresses the volume’s focus: the social and societal context of digital archaeological practice as structural and formative factors which shape its successes and limitations. The chapters which follow each set out social theories which help us to consider and understand how specific communities of digital archaeological practice form, develop and change in connection to their broader institutional, disciplinary and societal communities. Collectively, they describe a range of areas of digital practice where things are consistently not quite working out the way we think they should, linked by shared problems whose root causes – implicitly – are Silicon Valley style techno-optimism and winner-takes-all competitiveness. These illustrations of how the impacts of late-stage capitalist digitalisation are playing out, when read in the context of Kalaycı and Hacıgüzeller’s call to action, support the case for a radical new set of digital archaeological practices operationalised in a different socio-technical context.

Research specialisms within digital archaeology and heritage in which promises are being made and not kept, and in which progress should happen but somehow isn’t happening at a satisfactory pace, as defined by the collection of chapters include:

- Data harmonisation and interoperability as framed by FAIR and CARE data principles (ch.3)
- Mediterranean fieldwalking and regional survey data integration as an example of ‘big data’ driven integration projects (ch.4)

- Modelling based in bio-geochemical analyses, specifically isotope analysis, as an example of the benefits of scientific methods (ch.5)
- Computer vision and deep learning / machine learning as a means of analysing and interpreting large scale data (ch.6)
- Simulation, specifically agent-based modelling, as a means of understanding complex systems (ch.7)
- Gaming as a tool to think with and to promote engagement with heritage and archaeology (ch.8)

Wansleeben, Laan and Visser’s chapter discusses the reasons behind the very limited uptake of a standard XML form which was intended to improve the harmonisation, interoperability and discoverability of ‘grey’ archaeological data in the Netherlands and to standardise reporting. Anyone who has read Latour’s *Aramis and the Love of Technology* will find their analysis of the difficulties involved to be familiar. There were (§ 3.4) “practical problems” encountered when implementing and using the *pakbon* system. Troubleshooting was difficult, error messages when running a data validator were not clear and explicit, and not enough funding was available for the users’ organisations to build or purchase the software tools necessary to produce *pakbon* compatible data. Despite the system’s obvious issues, the *pakbon*’s developers were unwilling to abandon it because of its sunk costs. To quote the authors, “We already passed a point of no return, it has already been implemented by too many large organizations” (§ 3.5). Today, it seems, the *pakbon* is officially too big to fail and must be bailed out. A series of limited adaptations, new tools, and repurposing actions are proposed by the authors, even as they admit that even these may not resolve the *pakbon*’s usability problems and allow its benefits to come to the fore. The authors’ suggestion that a voluntary community effort is the route to resolving these practical problems points to the influence of the underlying constraints highlighted by Kalaycı and Hacıgüzeller: lack of financial resource to support the necessary software development, user training, software tool development, and staff time to make the *pakbon* system workable. The case of the *pakbon* raises important questions about the implications of the role of voluntary work, in the spirit of open source and open science movements, within a commercial archaeological and heritage management context.

De Haas and van Leusen focus on a related problem, outlining how the lack of standardisation in documenting fieldwalking surveys conducted in the Mediterranean region limits researchers’

ability to conduct the integration work and synthetic analyses needed to address ‘grand challenge’ research agendas and, further, reduces the data’s reusability. They discuss the benefits of various approaches to data integration before turning to the usual suspects which explain why such projects are not happening apace: lack of incentives and rewards for doing the work, lack of financial resources for undertaking the work, and lack of compelling reasons to enforce or adhere to standards. Funding agencies, academic and professional institutions, and state sponsored repositories are noted as key agents of potential change. Again, the reflections presented by the authors hint at the need for changes in the context in which we practice. In particular, systemic changes to the system of rewards and incentives for academic researchers are needed to enable meaningful progress on the specific problems of digital Mediterranean survey data.

The ongoing pursuit of new methods and drive to innovate appears again in the reflections of Laffoon and Sonnemann. In their chapter, they look at the promise of a scientific technique – isotope analysis and the production of isoscapes – to resolve a longstanding research question, and at the difficulties encountered in practice when applying it. For these authors, and for Klassen, Pappagallo and Evans in their assessment of the applications of deep learning in archaeological remote sensing, the imperative to innovate is palpable. The application of new methods and tools has led to real improvements in practice and in analytical results. Despite difficulties encountered, skills gaps, or unresolved research problems in domains outside archaeology which need to be resolved before progress can be made, there’s a determination to press forward. That said, Laffoon and Sonneman strike a cautious note in their conclusions, highlighting the limited real contribution of an innovative method to their project. Together, these contributions should prompt us to question the assumptions we make about the value of innovation, which are deeply rooted in the values of our wider societal context.

Romanowska and Scherjon’s assessment of current practice in agent-based modelling (ABM) focuses on the community of modellers themselves and what is limiting their wider impact within archaeology. In analysing networks of ABM users, they reflect on how the community of modellers is connected to the broader, beyond-digital archaeological, community. Again, while modelling and modellers have brought much to archaeological research, systemic limitations are highlighted as obstacles to further progress or as future risks. Shortfalls in training, mismatches between how

different parts of the community work, particularly in how they formulate their questions, and critically, the need to formalise our models and to align with dominant paradigms in science and data science are underscored. In this contribution, the role of communication between digital and domain specialists is emphasised, and the lack of a common language and shared understandings is cited as a notable barrier. Another impact of the ABM’s wider operational context appears more subtly: the need to align with the expectations of the ‘public and policy makers’ and to confirm archaeology’s ‘societal value’ in specific ways defined by that broader society mean that digital practices are shaped by external pressures to be more ‘scientific’ and ‘technological’. These tendencies don’t always match well with the expectations of archaeological researchers, particularly those trained primarily within humanities-led communities, and can lead to communication gaps which, in turn, limit the potential impact of ABM as a method through collaboration with archaeological specialists with relevant research questions and expertise.

The practice of archaeogaming, as explored by Politopoulos and Mol touches on further limitations created by under-resourcing. They consider the phenomenon of projects and blogs which have become inactive, questioning how to motivate the continued investment of time, energy and creativity needed to sustain and grow this specialist community. They point to the academic climate and its sometimes rather unforgiving attitude toward failure as an impediment to creative and experimental digital practice. Their contribution clearly captures how the societal paradigm in which ‘successes are what counts’ limits the ability to do new, good, work through taking intellectual risks.

‘Digital Archaeology: Promises and Impasses’ is one of several recent collections reflecting on digital practice in archaeology and heritage studies. Edited collections by Garstki (2022) and Goldstein and Watrall (2022) likewise aim to provide critical perspectives on a range of specialist topics while providing examples of emerging research and reflections on past projects. The unique contribution of this volume lies in how its chapters collectively sketch out the subtle but significant impacts of the wider context in which digital work is conducted. Each chapter focuses on the specific successes and obstacles faced by researchers and practitioners in the specialism it treats, highlighting progress, imperfect though it is, compromises made, workarounds devised, and what has been and can be done to take advantage of the affordances of the digital and the ways it can improve our working situation. While broadly the authors contributing to this volume paint an optimistic

picture, collectively they point to shortages in access to resource and training, failures in how we communicate with each other, the absence of appropriate job or career progression opportunities, and other contextual factors.

So, what can we conclude from these reflections and what do they contribute to the discourse? Do we agree that the shared root problem is the late-stage capitalist model? If we take this as true, what do we do about it? Do we refuse to play because we don't like the game? Do we persevere as well as we can, while maintaining consciousness that we are 'working within the system'? Do we work subversively, intentionally dismantling as we go, adopting a hacker mentality? Is it worth trying to address the smaller problems piecemeal? Is engaging with changing processes and practices within our control a good use of time?

Kalaycı and Hacıgüzeller, at least, propose to address the big picture problems, calling for the definition of a new "social theory of the digital" to provide the conceptual tools necessary to shift the current social-technical paradigm within digital archaeology. They describe an action-oriented theoretical project which will go beyond detached explanation of the current social phenomena connected with digital archaeology, providing a means through which a different system can be envisaged and enacted.

This volume, however, stops short of making proposals for a substantive new social theory of the digital, though citing Ossewaarde (2019), whose work provides an indication of the direction in which their proposed theory might tend. This is left as work for the future or, perhaps, as an exercise for the reader. In attempting to envisage starting points for such a theoretical project, we can turn to current social theories of the digital for inspiration. Contemporary social theory draws on the thinking of individuals whose names are familiar in archaeological circles, including Derrida, Foucault, Bourdieu, and Giddens, and theories explicitly focused on the intersection of the social and digital have been promoted by the work of thinkers including Latour, Haraway, Lanier, and D'Ignazio and Klein.

Latour is widely cited in archaeology for his work on actor-network theory (Latour 2007), and while his early fictionalised ethnography of the failures of the RATP to implement an automated train system (Latour 1996) is less central to the canon, its core tenets are implicit in it and in symmetrical archaeology, focusing on balancing thinking on the social construction of technological artefacts and the technical construction of social networks and bonds.

Aramis highlights, in addition to the entanglements of people and machines, the role of emotions, love and enthusiasm in social interactions with technological projects, emphasising that what we take joy from will shape our work. Like some of the theorisation of archaeogaming, and Perry's work (Perry 2019), it points to emotional satisfaction as a core aim of archaeological and technological practice.

Haraway's works, particularly *Cyborg Manifesto* and *Staying with the Trouble* (Haraway 1985, 2016), appear in the writing of scholars engaged in the theorisation of digital archaeological practice (e.g., Díaz-Guardamino and Morgan 2019; Huggett 2015; Huvila 2021; Morgan and Eve 2012; Morgan 2019) and notably appear in work by contributors to this volume (Hacıgüzeller 2012; Mol 2020). Her work, as taken up in digital archaeology, points to a focus on the process of becoming and the use of digital technologies to blur and cross boundaries, and on the potential of using our digital archaeological methods and tools to engage in the production of archaeological interpretations as science fiction. Morgan argues that [digital] "archaeologists should cultivate an alternative, posthuman feminist practice that dives into the uncanny valley, highlights chronological disruptions, that queers and interferes with our understanding of ourselves and the past" (Morgan 2019). Again, this is a shift in the implicit aims of socio-technical projects and a different measure of what constitutes 'good work' and 'success'.

Lanier, perhaps best known as an early proponent of virtual reality, argued that digital media at their best were used to produce reality with other people. His work, like that of Haraway and Latour, discusses the complexities of human-machine partnerships. He emphasizes human-digital technology's capacity to create experience and the links between this and the ability to generate new concepts of identity, community, and reality (Lanier 2014, 2018). His more recent work has criticised the concentrations of power within digital networks, and argues that, "in order to make tech into something that empowers people, people have to be willing to act as if we can handle being powerful" (Lanier 2018, p. xxviii) and explicitly considers how to balance the costs and benefits of digital networks and the 'free' information they carry.

D'Ignazio and Klein's work undertakes a parallel exploration of the connection between data science and human power (D'Ignazio and Klein 2020), specifically looking at the connections between who is in a community of practice, whose interests it

represents, and how data science and technological applications can mask the human interests embedded in them. They formulate the use of digital methods to gather, parse, interrogate and communicate data as an ethical issue. Their work highlights the pervasiveness of digital data and its manipulation throughout our social lives.

A glance across just these few bodies of work should provide some confidence that there's an active discourse around social theories of the digital, on which the digital archaeology community continues to draw. Indeed, as stated by Marres (2017) today, the digital constitutes a "total social fact" and any social theory about contemporary society encompasses it, providing an even wider body work from which to take inspiration and in which to ground our digital archaeological work.

In my own view, a new theoretical framework will be necessary but insufficient to transform digital archaeological practice and address the pervasive issues raised by the contributions in this volume. To bring in another metaphor, 'rocket science is easy; rocket engineering is really difficult'. Establishing a theoretical framework which explains how a system should work and how its various components interrelate is essential, but the implementation phase, this saying implies, is where many challenges lie. Even with better training in a range of technical skills, more resource to compensate people for their labour, less pressure to continually innovate, improved communication and collaboration between groups, and redefined aims inspired by a social theory of the digital, implementations of digital methods would have their difficulties: a range of small and large practical problems which must be addressed for things to work as they theoretically should. This is not a pessimistic conclusion, as there can be benefits in encountering these implementation problems. How to apply a model or best use a tool will be specific to each project and consequently a degree of flexibility is essential to digital archaeology. The issues which emerge because flexibility is built into general models create spaces for creativity and experimentation. These spaces are where we "fail gloriously" (Graham 2019) to live up to our own ambitions for our digital projects. If we are looking to step outside the current paradigm, driven by myths of unadulterated success and continuous improvement and growth, into one with a different underlying logic, then more space for focussing on processes rather than outcomes, and for the glorious and inglorious failures which occur while doing so, may be not such a bad thing.

REFERENCES

- Caraher, W. 2019. "Slow Archaeology, Punk Archaeology, and the "Archaeology of Care"". *European Journal of Archaeology* 22: 372-85. DOI:10.1017/eea.2019.15.
- Cobb, H., and R.J. Crellin. 2022. "Affirmation and Action: A Posthumanist Feminist Agenda for Archaeology". *Cambridge Archaeological Journal* 32: 265-79. DOI:10.1017/S0959774321000573.
- Cook, K. 2019. "EmboDIYing Disruption: Queer, Feminist and Inclusive Digital Archaeologies". *European Journal of Archaeology* 22: 398-414. DOI:10.1017/eea.2019.23.
- Dennis, L.M. 2020. "Digital Archaeological Ethics: Successes and Failures in Disciplinary Attention". *Journal of Computer Applications in Archaeology* 3: 210-18. DOI:10.5334/jcaa.24.
- Díaz-Guardamino, M., and C. Morgan. 2019. "Human, Transhuman, Posthuman Digital Archaeologies: An Introduction". *European Journal of Archaeology* 22: 320-23. DOI:10.1017/eea.2019.26.
- D'Ignazio, C., and L.F. Klein. 2020. *Data Feminism (Strong Ideas)*. Cambridge, MA, USA: MIT Press.
- Flexner, J.L. 2020. "Degrowth and a Sustainable Future for Archaeology". *Archaeological Dialogues*, no. 27: 159-71. DOI:10.1017/S1380203820000203.
- Fredheim, L.H. 2020. "Decoupling "Open" and "Ethical" Archaeologies: Rethinking Deficits and Expertise for Ethical Public Participation in Archaeology and Heritage". *Norwegian Archaeological Review* 53: 5-22. DOI:10.1080/00293652.2020.1738540.
- Garstki, K. 2022. "Critical Archaeology in the Digital Age". In *Proceedings of the 12th IEMA Visiting Scholar's Conference*. Bristol, CT (USA): ISD. <http://digital.casalini.it/9781950446261>.
- Goldstein, L., and E. Watrall. 2022. *Digital Heritage and Archaeology in Practice: Data, Ethics, and Professionalism*. Gainesville: University Press of Florida. <https://muse.jhu.edu/book/101232>.
- Graham, S. 2019. *Failing Gloriously and Other Essays*. Digital Press Books. DOI:10.31356/dpb015.
- Hacıgüzeller, P. 2012. "GIS, Critique, Representation and Beyond". *Journal of Social Archaeology* 12: 245-63.
- Haraway, D.J. 1985. "A Cyborg Manifesto – Science, Technology, and Socialist – Feminism in the Late Twentieth Century". *Socialist Review (US)*.
- Haraway, D.J. 2016. *Staying with the Trouble: Making Kin in the Chthulucene*. Duke University Press.
- Huggett, J. 2015. "A Manifesto for an Introspective Digital Archaeology". *Open Archaeology*, 86-95. DOI:10.1515/opar-2015-0002.

- Huggett, J. 2019. "Resilient Scholarship in the Digital Age". *Journal of Computer Applications in Archaeology* 2: 105-19. DOI:10.5334/jcaa.25.
- Huvila, I. 2021. "Monstrous Hybridity of Social Information Technologies: Through the Lens of Photorealism and Non-Photorealism in Archaeological Visualization". *The Information Society* 37: 46-59. DOI:10.1080/01972243.2020.1830211.
- Lanier, J. 2014. *Who Owns the Future?* Simon and Schuster.
- Lanier, J. 2018. *Dawn of the New Everything*. Picador.
- Latour, B. 1996. *Aramis, or the Love of Technology*. Harvard University Press.
- Latour, B. 2007. *Reassembling the Social: An Introduction to Actor-Network-Theory*. OUP Oxford.
- Marres, N. 2017. *Digital Sociology: The Reinvention of Social Research*. Polity Press.
- Mol, E. 2020. "Roman Cyborgs! On Significant Otherness, Material Absence, and Virtual Presence in the Archaeology of Roman Religion". *European Journal of Archaeology* 23: 64-81. DOI:10.1017/eea.2019.42.
- Morgan, C. 2019. "Avatars, Monsters, and Machines: A Cyborg Archaeology". *European Journal of Archaeology* 22: 324-37. DOI:10.1017/eea.2019.22.
- Morgan, C. 2021. "An Archaeology of Digital Things: Social, Political, Polemical". *Antiquity* 95: 1590-93. DOI:10.15184/aqy.2021.125.
- Morgan, C., and S. Eve. 2012. "DIY and Digital Archaeology: What Are You Doing to Participate?" *World Archaeology* 44: 521-37. DOI:10.1080/00438243.2012.741810.
- Ossewaarde, M. 2019. "Digital Transformation and the Renewal of Social Theory: Unpacking the New Fraudulent Myths and Misplaced Metaphors". *Technological Forecasting and Social Change* 146: 24-30. DOI:10.1016/j.techfore.2019.05.007.
- Perry, S. 2019. "The Enchantment of the Archaeological Record". *European Journal of Archaeology* 22: 354-71. DOI:10.1017/eea.2019.24.
- Perry, S., J.S. Taylor, M. Matsumoto, and E. Uleberg. 2018. "Theorising the Digital: A Call to Action for the Archaeological Community". In *Oceans of Data: Proceedings of the 44th Conference on Computer Applications and Quantitative Methods in Archaeology*, 11-22. Archaeopress Oxford.
- Richardson, L.-J. 2018. "Ethical Challenges in Digital Public Archaeology". *Journal of Computer Applications in Archaeology* 1: 64-73. DOI:10.5334/jcaa.13.
- Wright, H., and J.D. Richards. 2018. "Reflections on Collaborative Archaeology and Large-Scale Online Research Infrastructures". *Journal of Field Archaeology* 43: S60-67. DOI:10.1080/00934690.2018.1511960.
- Zorzin, N. 2021. "Is Archaeology Conceivable within the Degrowth Movement? 28". *Archaeological Dialogues*, 1-16. DOI:10.1017/S1380203821000015.

DIGITAL ARCHAEOLOGY

Archaeology has gone digital for some time now! Topics such as GIS databases, 3D models, drone photography, meta- and para-data, semantic mapping, text mining, simulation, and social network analysis have become commonplace in archaeological discourse and practice. Digital and technological advancements seemingly offer limitless promises for data recording, analysis and dissemination. Yet, after several decades of innovation, we must ask ourselves which of these promises are actually fulfilled, and which persistent impasses are present. Today, some reflexive questions are more important than ever. In particular, when, how and why do our innovative archaeology tools fail? Do we approach our archaeological projects with a digital wand and (implicitly or explicitly) expect a magical solution? And when there is indeed a digital solution, at what expense does it come?

In this volume, scholars and practitioners in the field discuss the state of the art, as well as the promises and impasses that digital approaches to archaeology entail. The authors discuss the current state of teaching digital archaeology, the societal impact of digital innovations, current issues in archaeological data management, promises and limitations of isotopic research and remote sensing techniques, and why subfields such as agent-based modelling and serious gaming struggle to keep momentum.