The Impact of Human Decision-making on the Research Value of Archaeological Data

MICHAEL LEWIS, University of Helsinki and British Museum, Finland and UK
ELJAS OKSANEN, University of Helsinki, Finland
FRIDA EHRNSTEN, National Museum of Finland, Finland
HEIKKI RANTALA, Aalto University, Finland
JOUNI TUOMINEN, University of Helsinki and Aalto University, Finland
EERO HYVÖNEN, Aalto University and University of Helsinki, Finland

'Good data in, good data out' is a well-known saying, though (traditionally) used to consider the 'precision' of data entry, rather than other human activity when inputting information into a database. These could be omissions or errors, but just as likely inconsistencies in data recording. This is especially relevant when thinking about 'efficiencies' that recorders might make (i.e., to make their work easier), what this might mean for end users (e.g., researchers), and/or (even) concerning data migration. For example, a recorder of a single-object type, such as a 'coin' or 'badge' might do things differently based on their knowledge or understanding of the value of recording certain types of data and how this information is likely to be used by others. In a database of 'coins', for instance, what is the point of adding 'coin' as a type if all the items are coins? However, if that data is migrated with other data, the lack of defining the 'object type' could radically affect that dataset. Hence, a simple human decision, even if logical, can impact data and its research value. With this in mind, this paper will consider the impact of human decision-making on the research value of archaeological data, taking (as a case study) the Portable Antiquities Scheme (PAS) database of archaeological finds from England and Wales.

CCS Concepts: • **Information systems → Web searching and information discovery**; • **Applied computing → Arts and humanities**.

Additional Key Words and Phrases: archaeology, data, databases, finds recording, portable antiquities, material culture.

ACM Reference Format:
Michael Lewis, Eljas Oksanen, Frida Ehrnsten, Heikki Rantala, Jouni Tuominen, and Eero Hyvönen. 2024. The Impact of Human Decision-making on the Research Value of Archaeological Data. *ACM J. Comput. Cult. Herit.* 1, 1 (May 2024), 19 pages. https://doi.org/10.1145/nnnnnnn.nnnnnnn

1 INTRODUCTION

Databases are generally created with the needs of primary users in mind, considering (in particular) how they will use them and what they might wish to extract from them. Thereafter, database developers might consider the needs of other potential communities, but not usually to the detriment of primary users. This might mean a

Authors' addresses: Michael Lewis, University of Helsinki and British Museum, Helsinki and London, Finland and UK, michael.lewis@helsinki.fi; Eljas Oksanen, University of Helsinki, Helsinki, Finland; Frida Ehrnsten, National Museum of Finland, Helsinki, Finland; Heikki Rantala, Aalto University, Espoo, Finland; Jouni Tuominen, University of Helsinki and Aalto University, Helsinki, Finland; Eero Hyvönen, Aalto University and University of Helsinki, Espoo, Finland.

1556-4673/2024/5-ART $15.00
https://doi.org/10.1145/nnnnnnn.nnnnnnn

database holds useful information for other people, but whether it can be easily extracted and exploited in full depends upon the application.

For example, a numismatist might create a database of coin data for their use. It is obvious to them that all the items are coins, so might not record that basic fact. Similarly, they might know that certain denominations – e.g., English medieval pennies – are of a particular composition (i.e., silver), so omit that detail. Also, some coins are so well classified that a reference number – e.g., Class 2b, as used on sterling 'long-cross' pennies – overrides the necessity to add related descriptive information (simply for the sake of making efficiencies in entering data), such as the exact form of the king's image (the number of curls in the hair, pellets on the crown, etc.). Furthermore, the creator of such a database might not foresee (or consider important) its use by another, where this 'missing' information might be seen as an omission, especially if this data is migrated to a database of non-numismatic material. In this case, it would be impossible for new users to search for items made of silver or that depict crowns. Such issues might seem obvious but are often overlooked and are therefore important to consider, especially given heritage databases can have long lifespans and the chances are growing (given the desire to log data and extract information from old datasets) that other users might wish to migrate old data for a different purpose than originally indented. Whilst it might be thought that these issues are easy to address (and that might be true in some instances), the following discussion will show that human decision-making in the establishment of databases, but also the recording of archaeological finds, can substantially impact its research value.

These decisions are fundamentally important when aiming at making data 'Findable', 'Accessible', 'Interoperable' and 'Reusable' according to the widely accepted and used modern FAIR principles [43][1] for creating Findable (F1–F4), Accessible (A1–A2), Interoperable (I1–I3) and Reusable (R1) data:

- *Findability*: F1. (Meta)data are assigned a globally unique and persistent identifier; F2. Data are described with rich metadata (defined by R1 below); F3. Metadata clearly and explicitly includes the identifier of the data they describe; F4. (Meta)data are registered or indexed in a searchable resource.
- *Accessible*: A1. (Meta)data are retrievable by their identifier using a standardised communications protocol; A2. Metadata is accessible, even when the data are no longer available.
- *Interoperable*: I1. (Meta)data uses a formal, accessible, shared and broadly applicable language for knowledge representation; I2. (Meta)data uses vocabularies that follow FAIR principles; I3. (Meta)data includes qualified references to other (meta)data.
- *Reusable* R1. (Meta)data are richly described with a plurality of accurate and relevant attributes.

Crucial decisions to be made for creating FAIR data include:

(1) What kind of functionalities and services are needed from the end user's point of view?
(2) What (meta)data model [35, 44] to use for describing the artifacts, e.g., Dublin Core[2] or its derivatives, CIDOC CRM,[3] or its extensions, such as CRMarchaeo[4] and Nomisma?[5]
(3) What 'controlled vocabularies' [15], i.e., Knowledge Organization Systems[6] (KOS) [45], are used in populating the metadata element values (e.g., for object type, material, time/period, place of manufacture, findspot etc.).[7] There are several options available, such as the Getty Art & Architecture Thesaurus[8] for artefacts and

[1]The FAIR principles are listed here and their numbering are based on https://www.go-fair.org/fair-principles/
[2]https://dublincore.org
[3]https://cidoc-crm.org
[4]https://www.cidoc-crm.org/crmarchaeo/home-3
[5]https://nomisma.org
[6]https://www.isko.org/cyclo/kos
[7]Here we use 'controlled vocabularies', 'thesauri', 'ontologies' and 'typologies' as synonymous terms, to mean a structured language.
[8]https://www.getty.edu/research/tools/vocabularies/aat/

PeriodO[9] for times and periods that were used as harmonizing linked data thesauri in the Pan-European ARIADNEplus infrastructure and portal.[10]

(4) What practices are used for cataloguing the artefacts?[11] For example, what metadata fields are required and optional, what kind of (and how detailed in content) descriptions are needed, and how to represent uncertain dates [12] and express them etc. Cataloging practices are especially well-developed for bibliographical records.[12]

Once decisions on points (1) and (2) have been made, and the database user interfaces are implemented, points (3) and (4) remain practical challenges, as the specifications for creating the database typically leave scope for users to input data in various ways. This is especially true when using string-based annotations and textual descriptions that are ambiguous to a machine. A remedy is to use controlled KOS with unique identifiers, but even then quality issues arise, as the KOS are seldom complete and different users tend to make individual selections based on what seems logical to them, leading to low inter-annotator agreement [1]. The challenges are emphasised when lots of different users, especially those without a professional cataloguing/recording background, are inputting data, e.g. as in 'citizen science archaeology' [36], of which the PAS database (see below) is a good example.

While those developing archaeological databases are likely to have a more rounded view of how end users might use that data, this paper will show that human decision-making can impact data value. Although controlled language and drop-downs might be used to group and harmonise data, as well as limit the risk of human error,[13] these tools are not fool-proof guarantees for capturing high-quality data. Similarly, training database users, as well as providing clear documentation (metadata or otherwise), that offers consistent guidelines and is an authoritative point of reference, might be an obvious way of ensuring consistency in data inputting. Invariably, however, users will develop bad habits, such as failing to complete certain fields or choosing inappropriate drop-downs, through ignorance or incompetence.

Here, we take the Portable Antiquities Scheme (PAS) database[14] of archaeological finds made by the public in England and Wales, as an example of a dataset to trial in terms of how human decision-making can alter the research value of data. This is not designed to be a criticism of the database, especially as the issues identified here are by no means unique to it, but it provides a good platform for this analysis for several reasons. First, it is a large archaeological dataset, one of the largest in Europe, of over 1.7 million finds of all types and periods. Second, the data has been inputted by many people, 1,175 since 1997, and these 'recorders' will have varying skills, experience and expertise. Third, the people entering the data are based across England and Wales, and therefore might have or have developed (as will be shown) regional approaches to their work because of varying demands. That said, the processes for entering data into the PAS database are relatively robust: it follows a common thesaurus in terms of logging finds types (and sub-types etc); it makes good use of drop-downs to encourage fields to be completed consistently; its staff, assistants, interns and volunteers are all trained in recording finds on the database; and there are guides on how recorders should enter specific data.

As part of this study, not only was the PAS database interrogated but also a large sample of that data (981 834 finds records, downloaded on 9 July 2021), were imported for analysis. This sample data has been analysed for this paper using the R[15] language. Additionally, a web application, based on the Sampo-UI[16] framework, known

[9]https://perio.do
[10]https://ariadne-infrastructure.eu
[11]e.g., https://www.getty.edu/research/tools/vocabularies/cco_cdwa_for_museums.pdf
[12]Cf., eg., https://www.ala.org/pla/resources/tools/circulation-technical-services/cataloging-practices
[13]'Dropdowns' on the PAS database include 'object type' for example, where users can only use the options available.
[14]PAS database: https://finds.org.uk/database
[15]https://www.r-project.org/about.html
[16]See the source code of framework at https://github.com/SemanticComputing/sampo-ui.

as PASampo, was used to quickly explore and visualise the data. Mainly for this application, a simple RDF[17] format conversion of the data was created. Some of the analyses and visualisations presented here are created using the application and the RDF data. The most current root data in the PAS database has also been used where appropriate. As such, the research for this paper has been performed using multiple tools for exploring and analysing PAS data generated over 20+ years.

The PAS database is currently undergoing a rebuild (2023–25), hence the lessons learnt here are likely to be useful in its further development, and that of other archaeological databases also; more generally, there is a proliferation of such European databases for recording public finds, with some, such as in Denmark[18] and Belgium,[19] being dependent upon a citizen science approach [6, 41, 42]), driven by a recognition of the research value of public finds for advancing archaeological knowledge [34]. Even so, this paper offers a reminder to end users that data entry can cause biases, and it is useful for researchers to be aware of these when using any archaeological dataset.

The following two case studies (both of two parts) further the issues outlined above. One explores biases in data and the other examines the specifics of recording certain object types. Thereafter, will be explored how vocabularies impact upon data recording, aspects of data quality and semantic analysis.

2 CASE STUDY A: REGIONAL AND LONGITUDINAL VARIATION IN DATA ENTRY

This case study will shed light on how large-scale multi-contributor archaeological databases may develop a lack of overall uniformity in data quality across their operational lifetime. Firstly, it will explore how and why the spatial precision of findspots (a critically important class of information) in the PAS database varies between regions. Secondly, how limited-term initiatives (here a drive to encourage the reporting of public finds of heavily corroded Roman coins, colloquially known as 'grots') may have a very positive yet uneven impact on the formation of the dataset, as well as introducing hidden biases that must be examined and understood if the data is to be reused for large-scale analysis.

2.1 Recording Spatial Precision

To interpret finds within their landscape context and to investigate their relationships to one another more generally, the precision of findspot data is of paramount importance. Metal-detected finds discovered by hobbyists are typically recovered from the ploughzone and therefore lack any stratigraphic context that aids in their interpretation. The broad spatial and landscape contexts are therefore crucial in their study [5, 41]. PAS findspot data, like most British archaeological spatial data, is recorded using the Ordnance Survey (OS) National Grid Reference system (NGR[20]). In this system, the NGR indicates the location of a square within which the find was made, with longer NRGs giving greater precision. As seen in Fig. 1, most finds are given as 6-figure (within 100m), 8-figure (10m), or 10-figure (1m) references, although a minority (mostly older finds) are less precisely recorded; before affordable hand-held GPS devices and smart-phone apps (so when findpsots were mostly taken from printed maps), more precise NGRs were hard to obtain. Since 2003, the PAS has required finders to give at least a 6-figure NGR (e.g., TQ123123), and more recently (since 2015) at least an 8-figure NGR (e.g., TQ12341234). In 2022, at least 82 percent of new finds were recorded to at least an 8-figure NGR, and 74 percent had at least a 10-figure NGR [21, p. 39]. Given that most 'portable antiquities' are from the plough-zone (93 percent in 2022), where they are likely moved from their original place of deposition by the action of agricultural machinery, this is regarded as a good working precision in most cases.

[17] https://www.w3.org/RDF/
[18] Digitale Metaldetektorfund (DIME): https://metaldetektorfund.dk/ny/
[19] Metaaldetectie en Archeologie (MEDEA): https://medea.weopendata.com
[20] https://epsg.io/27700

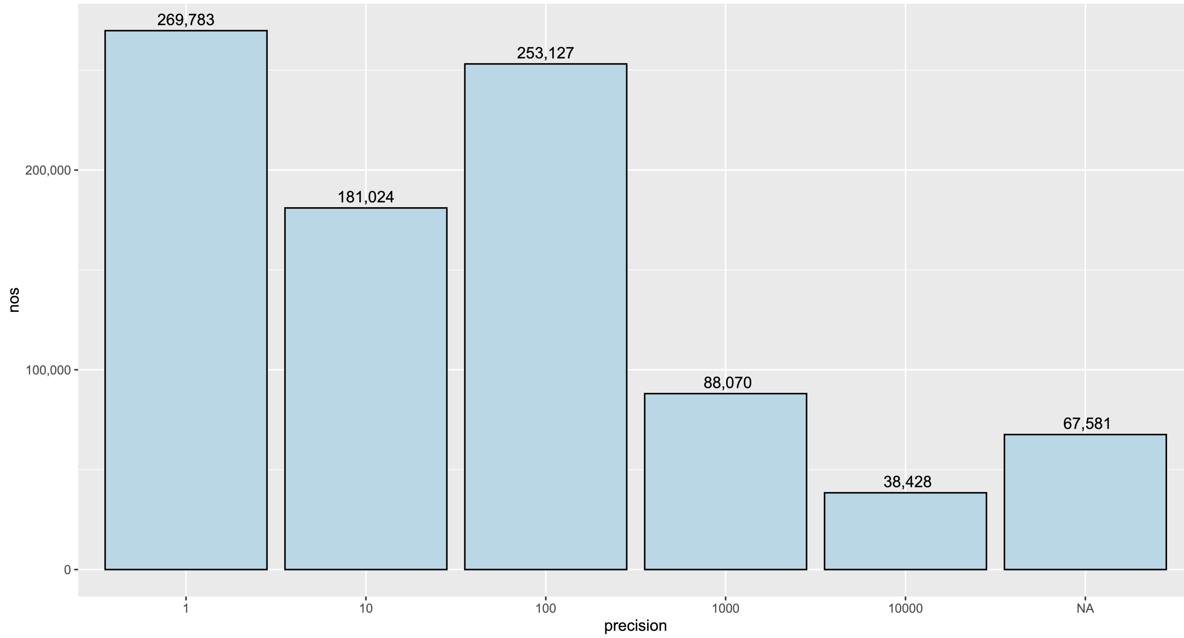

Fig. 1. PAS finds by NGR spatial precision. 1 = precise to 1 metre. A small number (855) of finds with greater given precision than 1 were rolled into that category.

Other factors impact on the character and quality of the data. Fig. 2 shows (on a yellow-green-blue colour scale) a mathematically calculated map surface laid over England and Wales. This illustrates a variation in the local recording of findspot precision, computed using the *Smooth* function of the R *spatstat* package.[21] Regions with no, or a very low density of, finds have been removed to even out statistical anomalies. The visualization shows clear regional variation across England and Wales. The Isle of Wight, on the south coast, and the majority of Wales, in the west, appear to have (on average) the most precise spatial data. Another major divide lies roughly between northern and southern England, with finds records from the south having better spatial precision. From this, it is possible to make several observations that illustrate the characteristics of the PAS database, with broader relevance to similar archaeological databases:

(a) Recording and community relations. The role of the local Finds Liaison Officer (FLO), who is primarily responsible for recording finds onto the database, is critical. The high spatial precision achieved on the Isle of Wight owes much to the work of a long-standing FLO (2003–2020) who had good relations with the local detecting community. By contrast, the high turnover of Essex FLOs (seven since 2003; the predominantly blue area on the south-eastern coast above the Thames estuary) and broader issues of some local detectorists being less willing to work with archaeologists, highlights the importance of continuity and ongoing liaison between archaeologists and finder communites, thus resulting in more and higher quality records[32].

(b) Reporting practice locally. Hundreds of recorders logging information from thousands of finders over more than 20+ years have contributed to the PAS database [3, 20]. The PAS was established on the back of long-term animosity between archaeologists and finder groups [20, 38], alongside finders in some areas (especially in the midlands and the north) being naturally suspicious of state institutions. This might be reflected in the difference

[21]R spatsat homepage: https://cran.r-project.org/web/packages/spatstat/

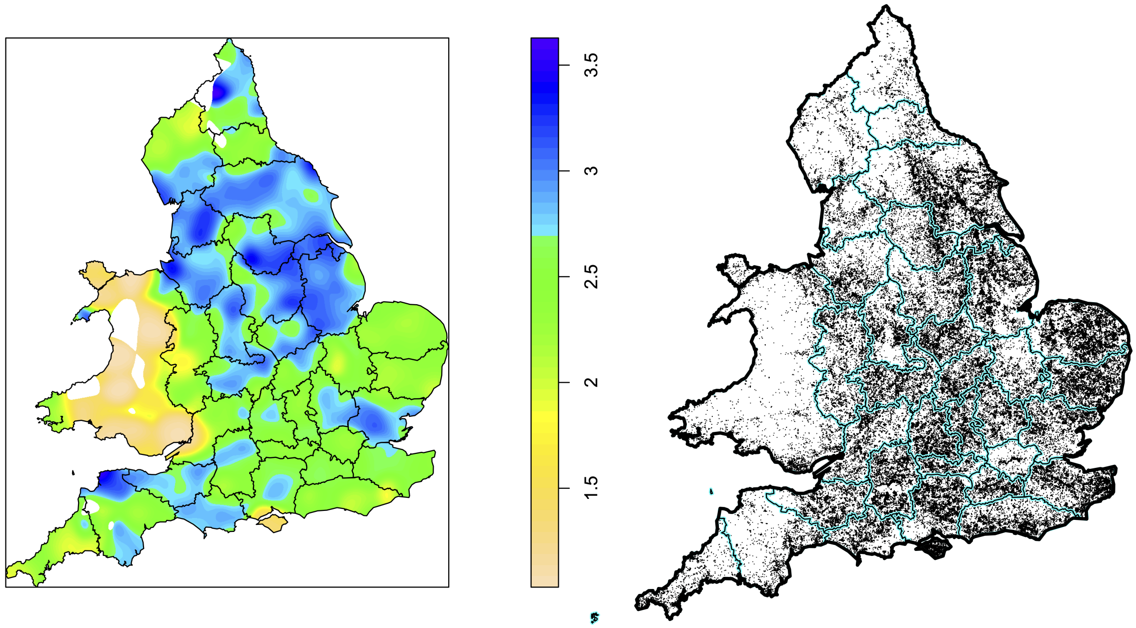

Fig. 2. Local average of findspot accuracy across England and Wales (sigma = 10 km), and the distribution of findspots with coordinate values (954 161). To assist with analysis and visualization, findspot accuracy has been translated so that the progression is not by an order of magnitude (1, 10, 100, etc.) but rather that 1 = precise to 1 m, 2 = 10 m, etc. Variation in values within the computed surface is therefore relative.

in findspot precision between northern and southern England, and (even now) FLOs in northern England note the reticence of high proportions of finders (compared to the south) withholding precise findspot information. It is also the case that finders in the south are more likely to make finds than in the far north – given the considerable differences in historical population densities and therefore the amount of material culture to be recovered (see e.g., [9, 27]) and therefore become more familiar (and comfortable) with recording with the PAS.

(c) Data harmonization. Merging external data dumps into a database without fully processing and harmonising them will create anomalies. The apparent high findspot precision in Wales is a product of the inclusion of records from the Celtic Coin Index[22] (CCI, 37 844 records), and the Iron Age and Roman Coins of Wales[23] (IARCW, 52 812 records) databases, added in 2010. These projects are external to the PAS yet amounting to almost 10 per cent of all PAS records, digitized coins from existing archives, excavation reports and other sources. It is of note that these data sources and recording practices vary from the workflows adopted by the PAS. In many cases, for example, the spatial coordinate associated with a given coin record is a high-precision spatial coordinate for the centre point of an excavation area, rather than the object's actual findspot. The CCI and IARCW coordinates are therefore no less precise, per se, but simply encode a different class of information – a difference that can be accounted for, but is not obvious to most end users.

[22]https://cci.arch.ox.ac.uk/pages/info
[23]https://doi.org/10.5284/1000263

2.2 Impact of Educational Outreach

The decision to report a find is the penultimate 'stage' that an object must pass on its journey from deposition to becoming a database record [32, 33].[24] This is typically informed by an appreciation of the archaeological, or other cultural heritage, value of the find. Roman coins are the most commonly reported find type in the PAS database (297 747 items, representing 30 percent of all finds). Many detectorists do not always see great individual value in the small late Roman copper-alloy coins that are found in particularly large numbers, especially if they are poorly preserved. The significant archaeological and numismatic value of these 'grots', however, lies in the possibilities they offer in charting *en mass* hitherto poorly understood patterns in the Roman economy and money circulation. Certain small-denomination copper coins are also very rare in Britain, with only a few examples known. Specific issues of low-denomination copper-alloy coins can even be linked to particular events, such as movements of the Roman Army, and may therefore yield singular evidence relating to these happenings; so far this research has concentrated on earlier Roman coinage, suggesting the still untapped potential present in expanding it to the later material. More generally, the significant numbers of Roman coins recorded by the PAS have been used to investigate economic developments, both regionally and across large geographical regions, including tackling such major topics as the end of Roman Britain [4, 24, 39, 40].

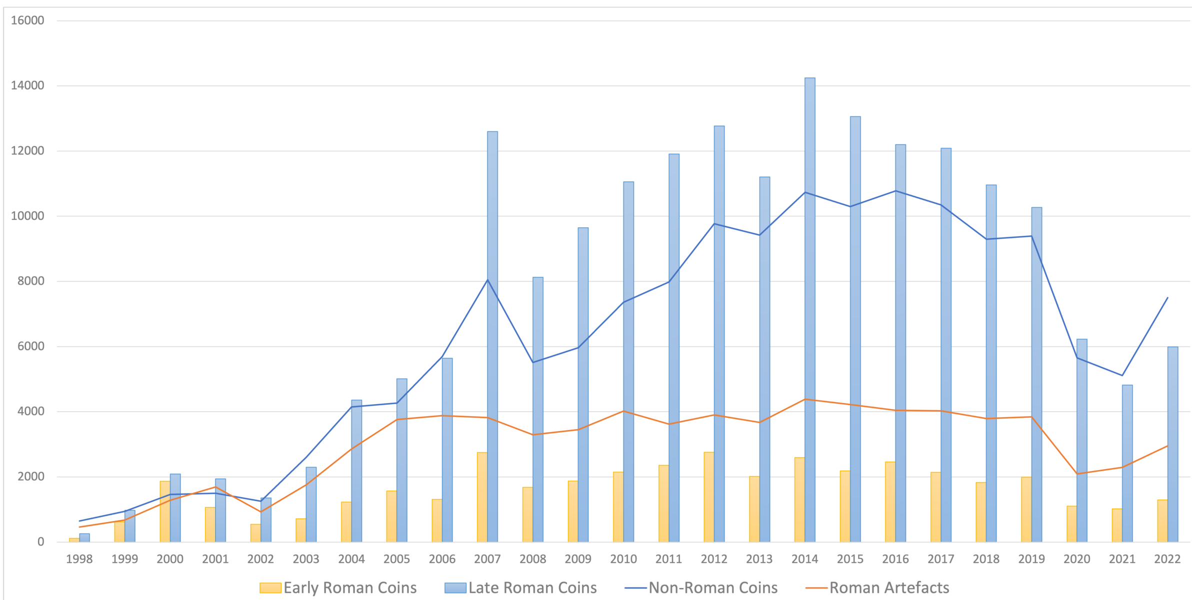

Fig. 3. Selection of different object types recorded in the PAS database 1998-2022. Data dumps from external projects have not been included in the figures.

The impact created by a short but concentrated educational outreach project on the PAS database can be most spectacularly seen in the case of these coins. In 2007, Sam Moorhead, then PAS National Finds Adviser for Iron Age and Roman Coins, embarked on a speaking tour of detecting clubs across the county promoting the reporting of Roman 'grots' [25, pp. 3–7]. The results are seen in Fig. 3, which displays a significant peak in recorded late Roman coins, from *c.* AD 238, Reece period 12 [30, 31],[25] during that year. It is noteworthy that while this does

[24]See also the PAS Guide for Researchers: https://finds.org.uk/research/advice
[25]https://finds.org.uk/romancoins/reeceperiods

not seem to have impacted upon the recording number of Roman non-coin artefacts, which has remained more or less static between the PAS becoming a national project in 2003 and the COVID-19 pandemic of 2020, there was an almost an equally impressive increase in coin records from other periods – numismatic data was put on the map on a new level. While the numbers came down the following year, there was a sustained overall annual increase in coins (both Roman and non-Roman, but especially late Roman coins) recorded in the database. The fact that large numbers of the coins recorded in 2007 had been discovered sometime before and not reported, is shown by the fact that the median date of discovery (when this information is recorded) for these coins is in September 2005, whereas for all other years (2003–2020) the reported time of discovery was either during that same year or in the last quarter of the previous year. The 'grot drive' was clearly a very successful educational enterprise, which significantly benefited archaeological and numismatic understanding of the past.

The data, however, was not digested by the PAS database without leaving characteristic traces. The result of detectorists handing over large collections of old finds led to lower-than-average quality of record data for that year. This is especially seen in Norfolk, where over 11 000 old finds were brought in for recording (cf.[17, p. 173]). 'Material' is one of the most consistently completed fields in the PAS database, with 98 percent of all records containing this information; for 2007 Norfolk coin records, the material field was left empty 95 percent of the time. Most records also do not contain an image of the find. In 85 percent of the 2007 Norfolk coin records with coordinate data (10 444) the NGR is given as a 10-figure reference (i.e., 1 m), but this is misleading as a closer examination shows that finds are stacked into only 1212 individual findspots. It was likely not possible to obtain good quality information on these older finds, some going back to the 1990s, and many collections (including some containing hundreds of coins) were lumped together with a single 'centre of field' findspot.

In a way, these collections of old finds can also be conceptualised as 'external data dumps', at least in the sense that they were reported and recorded using somewhat different principles than most of the other finds in the PAS database. This is not to denigrate the goodwill or effort put into creating this considerable amount of new information, one which possesses considerable research potential. But from a data management perspective such exercises can lead to problems with interoperability and reuse, especially given that the large amounts of data generated are attractive for computational archaeology (e.g., [2, 8]). Statistical and Geographic Information Systems analyses examining the spatial properties of the finds would yield skewed results if the special characteristics of the local data were not identified and controlled for. Yet, this information is unobtainable except through a targeted and fine-grained search for anomalous patterns in the PAS database as a whole and has to be known about by the researcher to be adequately processed and contextualised. This highlights the importance of documenting and publishing the process history of data creation in accessible metadata and paradata formats, as will be highlighted later on. This is especially true for large cultural heritage databases (see also [26]), where, as in the examples above, data creation conventions may have varied across their operational lifetimes.

3 CASE STUDY B: OBJECT TYPE CASE STUDIES

This case study will illustrate the complexities of recording certain object types and the potential impact this has on data for research. Firstly, are explored coins, which are particularly numerous within the PAS dataset, but also have to be approached somewhat differently because of certain, fairly unique, attributes. As such, they present a challenge when recorded in a dataset that also includes non-numismatic items. Secondly, is an examination of problems applying controlled vocabularies when certain artefact types might be open to varying interpretations, here exploring the case of religious and secular badges. Items that might seem similar, but are (perhaps) not.

3.1 Coins as Standardised Objects

As already shown, coins are common metal-detected finds. At times in the past when small-value coins were minted in large quantities there also tends to be a high proportion of coin loss. Accordingly, they have been reported in high numbers by the metal-detecting community in countries where detecting is legal [28]. In a monetised society, coins are primarily a means of exchange, with their most important feature being reliability (i.e., users of coins have to trust their face value, without retesting their weight and precious metal content). Throughout history, coins have retained their function as standardised objects; with some exceptions, they are invariably round and made of metal. The minting authority determined a coin's value, usually indicated through iconography and text on the coin, but also its size and weight. In addition to the value, coins can also name the ruler under which the coin was issued and the place where it was minted. These aspects which (in most cases, except for in debased small-change) guaranteed confidence in coinage for users hundreds of years ago are the same features which form the base for typologies used today when identifying and describing coins[14, p. 94]). These typologies have a long history, as the first coin collections in Europe were established during the Renaissance and coins were among the first objects to be accessioned into museums in the 18th century.

Because of the physical aspects of coins, the history of coin collecting and numismatics as a specific scientific discipline, the cataloguing and recording of coins may differ from other archaeological objects. There are established customs used when describing a coin, to create a complete picture of its physical attributes (e.g., material, manufacture, weight, diameter, die axis, etc.), geographic context (e.g., mint, region, findspot, etc.), issuing authority and other personal aspects (e.g., state, ruler, issuer, engraver, etc.), chronology (date), description (e.g., denomination, weight standard, as well as detailed descriptions of both the obverse, the reverse and the edge, etc.), and condition (wear and completeness). Standardized references are also widely applied,[26] and digital projects, such as Nomisma,[27] strive to provide stable concepts for recording coins within the principles of Linked Open Data, which can help to further harmonize numismatic data.

Coins have generally been mass-produced, they are easy to classify and for the finders today they are easily recognisable. Within PASampo (as derived from the PAS database for this study), coins (currently 499 555 entries) constitute 30 percent of the total. Most are described according to internationally used standards, with different dropdowns used to a varying degree. For the users, the advanced numismatic search based on different periods enables a detailed search for certain features of the coins, including information on, for example, the die axis, inscriptions etc. Material is documented in 97.6 percent of cases, weight in 72 percent, and diameter in 63 percent. Sometimes in the PAS dataset the diameter has been replaced by length or height, which are not standard values when cataloguing coins, highlighting the pitfalls and challenges of combining numismatic and non-coin data. The denomination field is well used when it comes to Roman coins, but for the Medieval period, it has been left out in 10 percent of the entries, see Fig. 4, presumably because the 'penny' was the standard silver coin in England for much of the medieval period (from c. AD 855 for the next 500 years).

Due to both the large number and the specific nature of coins, numismatic objects have achieved a special status in PAS data. There are separate numismatic guides and detailed recording schema designed to fit traditional numismatic research. The level of information used when recording coins understandably varies depending on the knowledge of the recorder and how much time they have to make a record. Although the recording of coins usually follows certain established practices, searching for certain aspects (especially outside traditional numismatic values, such as issuer, material and denomination) is more complicated. All the coins in the PAS dataset are primarily listed as objects of commerce, which is of course true, but a coin may acquire a secondary function during its life. These shifting roles can be difficult to identify especially for finds lacking a precise archaeological context (typical for detector finds), and therefore without extra information about why they have been deposited. Perforated (possibly used as dress accessories or amulets), folded (an action that can be interpreted as part of a ritual such as a pilgrimage offering), and clipped coins (indicating the object was valued

[26]How to catalogue, digitise, and move a collection of coins (Bibliothèque nationale de France): https://bnf.fr/en/how-catalogue-digitise-and-move-collection-coins-simple-tip
[27]https://nomisma.org

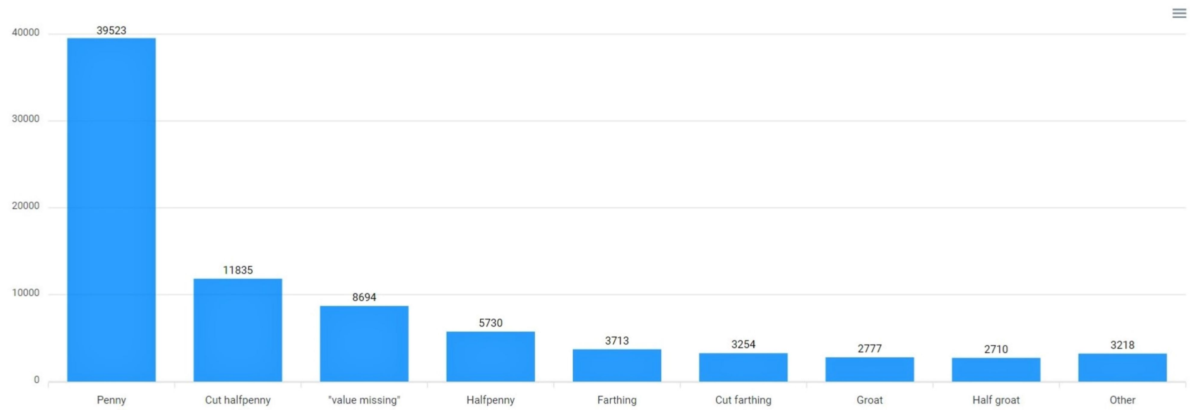

Fig. 4. The relative numbers of medieval coin denominations recorded in PAS.

principally as a store of precious metal, rather than for its formal face value) are the easiest to distinguish (see e.g., [13]); sometimes harder to observe is the difference between pre-dispositional damage and that made after, such as by the plough. In the PAS database, there are (perhaps unsurprisingly) no dropdowns for these types of values and the only way to locate items with these aspects is by using the free text search and opening individual records. This is a cumbersome process, not least as certain searches (like folded) will bring up hundreds of records, many of no relevance (such as coins showing figures with folded garments, rather than of folded coins).

Wear and completeness are also less frequently used values in the coin entries, with information lacking in 34 percent (163 861 cases, data from PASampo). The information of completeness is incomplete in itself, as it would require a further drop-down describing whether the coin has been accidentally broken or intentionally modified. Sometimes this value has even been used for coins that are simply extremely worn or misstruck, describing completely different phenomena. A more thorough use of dropdowns is time-consuming for the person recording such items, but on the other hand, it could reduce the need for free text descriptions. For already well-standardized objects like coins it would further minimize the risk of definitions open to interpretation.

3.2 Badges vs. Pilgrim Badges

The PAS 'finds guide' for 'pilgrim badges'[28] requires database users to record medieval pilgrim badges as a 'PILGRIM BADGE' (Fig. 6) in the 'object type' dropdown, as opposed to 'BADGE' (Fig. 7), which should be used for 'secular' and 'livery' badges.[29] An important point here is that the KOS are imperfect models for many items of material culture [11]. It might not always be obvious to a recorder if a badge is a religious badge or not, or even that this distinction between the religious and secular makes sense in terms of the medieval worldview, where the realms of religion and everyday life are blurred. Indeed, some (so-called) 'secular badges' are inspired by their 'religious' counterparts. Notable are badges of St George, which, unlike most pilgrim badges, are usually made of silver, suggesting that they might be 'secular' badges instead [19, 22]. Similarly, it has also been argued that 'profane badges', so usually depicting a phallus and/or vulva, or sex scenes, might have religious connotations [7]. Whatever the theoretical complexities determining whether a badge is a pilgrim badge or not (see [19, 37]), the guidance to those making records on the PAS database is clear (see above) – religious badges should be recorded

[28]https://finds.org.uk/counties/findsrecordingguides/pilgrim-badges/
[29]https://finds.org.uk/counties/findsrecordingguides/badges/

Fig. 5. Folded silver short cross penny of Henry II, c. 1180-1185, found in Houghton, Hampshire (PAS: SUSS-2714DD).

as pilgrim badges and other (secular) badges should be recorded as (just) badges. Nonetheless, it is apparent that this guidance is not always followed, creating issues for end users of this data.

Fig. 6. Lead-alloy medieval pilgrim badge showing the bust reliquary of St Thomas (Becket) of Canterbury, found at Millwall, London (PAS: LON-2B684D)

The PAS database has 769 finds records identified as 'medieval' (broad period) and 'pilgrim badge' (object type). A further 327 are 'medieval' (broad period) and 'badge' (object type). This suggests the latter should be medieval 'secular' badges, such as livery badges and similar. However, some recorders use 'badge' for items that

Fig. 7. Silver-gilt medieval livery badge showing a stag's head, found at Beal, North Yorkshire (PAS: SWYOR-625C53)

might be religious but cannot be identified with certainty. A 'badge' from Great Oxendon, Northamptonshire (LEIC-25DBA9; Fig. 8) is decorated with a likely female bust in profile. The recorder suggests this is 'possibly the Virgin Mary', but is clearly unsure, and rightly so. In the case of another badge, this time from Leckhampstead, Buckinghamshire (BUC-6E8E43), the image is hard to make out, although the recorder says the object is 'possibly a pilgrim badge' and might show St John the Baptist, St Veronica or St Thomas (Becket) of Canterbury!

Conversely, some items recorded as 'badges' are actually 'pilgrim badges', and have even been identified as such (even if not recorded as so). These include one showing the Annunciation, from Glemsford, Suffolk (SF-527947; Fig. 9), and another of the unofficial cult of Henry VI, found at Wakefield, South Yorkshire (SWYOR-E2D028). Here then, it would seem 'human error' has resulted in a 'pilgrim badge' being recorded as a (secular) 'badge'.

Fig. 8. Lead-alloy badge showing a likely female bust, perhaps the Virgin Mary, found at Great Oxendon, Northamptonshire (PAS: LEIC-25DBA9)

Usually, badges recorded as 'badge' are secular, and examples include several heart-shaped items (e.g., SWYOR-9132FB and NLM-28F731, etc.), usually interpreted as love tokens, but perhaps might be livery badges. A further complication is that not all badges are certainly badges. For instance, an 'unidentified object' from Dobwalls

Fig. 9. Lead-alloy pilgrim badge recorded as a badge showing a scene of the Annunciation female bust, found at Glemsford, Suffolk (PAS: SF-527947)

and Trewidland, Cornwall (CORN-98B552), has been recorded as a 'badge', though it appears to have a stud-like projection, more typical of 'mounts', rather than a pin or attachment loop. That said, it is like a pilgrim badge in terms of its composition and form, highlighting the limitations of the controlled vocabulary used.

It could be argued that the ambiguous (even incorrect) assignment of possible (or actual) religious badges as secular badges matters little, as a search of 'badge' on the PAS database brings up all the badges, both 'pilgrim badges' and 'badges', and its (very useful) 'filter' function then enables certain aspects to be excluded. However, with more and more data being added to the PAS database, it is becoming harder for researchers to find items if divorced from where they might expect to see them. This brings us to items recorded as 'pilgrim badges'.

Most of the items recorded as 'pilgrim badge' are religious, as might be expected, but there are some anomalies. Recorded on the PAS database is a heart-shaped pendant from Bradbury and the Isle, County Durham (DUR-F183F4), similar to the heart-shaped 'secular' badges mentioned above. Also, badges from Southwark and Queenhithe, London (LON-CA95FB and LON-1048B7), are in the form of a *gisarme* (axe-like weapon). It is not clear why these have been recorded as pilgrim badges rather than badges. Pendants also present a challenge for recorders, especially those that are badge-like. A series of lead-alloy pendants showing St Margaret of Antioch (on one side) with the 'IHS' monogram (on the other), which are particularly common in Lincolnshire (e.g., NLM-BECE1A, NLM-02E8A7 (Fig. 10) and LIN-4A9334) and therefore suggested to be associated with the local cult centre of Ketsby [18], have been traditionally recorded as 'pilgrim badges' though they are certainly pendants.

Some badges, often continental, have loops, which distinguish them from other pilgrim badges. Examples include those associated with St Eloi (YORYM-6BC577), St Guilhem (YORYM-F112E1) and St Peter and St Paul (NMS-D08520 and OXON-0C414B). Others, such as that in the form of a purse from Wickwar, Gloucestershire (GLO-E0E35D), are also perhaps religious – thought to be associated with St James 'the Great – but could be a 'secular' charm. Others are almost certainly secular, including a badge from Queenhithe, London (LON-104804), showing a female and male bust, each within a frame, with suspension loops above. Another object type sometimes finding its way amongst 'pilgrim badges' are *ampullae*, lead vessels to hold holy water or liquids (e.g., LANCUM-6A194E (Fig. 11) and LANCUM-0AB780), and even Canterbury bells (KENT-EC8680). In short, the items recorded as pilgrim badges show inconsistency in the use of that term, which makes the database harder to use for researchers and others.

Fig. 10. Lead-alloy religious pendant recorded as a pilgrim badge showing St Margaret of Antioch (on one side) and the Christogram IHS (on the other), found at Willoughby with Slootby, Lincolnshire (PAS: NLM-02E8A7)

Fig. 11. Lead-alloy medieval pilgrim's *ampulla* recorded as a pilgrim badge, found at Thornley, Lancashire (PAS: LANCUM-6A194E)

4 DATA VALIDATION FOR IDENTIFYING HUMAN ERRORS IN THE RECORDING PROCESS

Approaches for detecting human errors or finding anomalies in data inputted in databases include various data validation techniques. For example, recent advances in the context of Linked Data include Shapes Constraint Language (SHACL)[30] and Shape Expression Language (ShEx),[31] machine-processable languages for validating data against a set of conditions [16]. These integrity constraints specify the 'shape' that the data has to conform to for the data to be semantically valid. Based on these languages, there exists 'validation software'[32] that can be used to 'define' and 'check' parts of datasets, and (thereafter) produce a report that states whether the dataset conforms to predetermined 'shape definitions' and lists possible violations.

[30]https://www.w3.org/TR/shacl/
[31]https://shex.io
[32]E.g. Apache Jena SHACL: https://jena.apache.org/documentation/shacl/

As a case study, a small-scale data validation experiment has been made, using the PAS dataset within PASampo, focusing on the dates and periods. The PAS uses a broad period classification for finds, following FISH (Forum on Information Standards in Heritage) vocabularies, which includes (chronological) date ranges for 'archaeological periods'.[33] In addition, the PAS records individual finds (i.e., unique records with the PAS database, replicated with PASampo) with a date range ('from date' – 'to date') which allows for more precise temporal recording than using the broad period classification. To interrogate these data, a SHACL shape was created, that states that the 'from date' has to be 'less than or equal to' the 'to date'. When validating the data with a SHACL 'validator', it is possible to identify finds with a 'from date' that is recorded as later than the 'to date'. Such anomalies are probably human errors in the data recording process – e.g., incidents where the user has possibly mixed the from and to dates. This included some 2000 errors of this type, including, an Iron Age quarter *stater* (KENT-CC89C1) recorded with the date range AD 80–60 in error; the correct dating is 80–60 BC, as in the textual description of the find it where is stated that it was 'minted between c.80–60 BC'.

To investigate possible errors in the use of the period classification of the finds data, a SHACL shape that defines the 'from date' and 'to date' was created. This stated that finds cannot be dated earlier than the 'start date' or later than the 'end date' of a given period: thus, violations of the shape are cases where the 'from date' and/or 'to date' are outside the broad period's date range. In this example, it seems that violations are caused by human error, and therefore this tool can help ensure the integrity of the data and its future value for researchers.

Nonetheless, and adding to the complexities of mitigating against such human error, it is also evident that some 'apparent errors' are explained by conflicts between the 'broad period' classification (which considers items within a 'national' context) and the 'find date' (that is not necessarily linked to that). For example, it was found some 50 000 Roman coins violate the 'shape', since their 'from date' is recorded as earlier than the period's start date: examples include a silver *denarius* (SWYOR-717483) dated to 122 BC and a copper-alloy *sestertius* (SF-E324F3) dated AD 1–250. In both cases, human error does not explain the apparent inconstancy. Instead, the FISH classification for the Roman period – AD 43–410, based on the Roman occupation of Britain – is at odds with the fact that Roman coins were being manufactured centuries earlier. These Roman Republican coins were being imported into Britain, informing on earlier Roman activity before the Roman occupation of Britain. In a numismatic and historical sense, these coins are certainly Roman, even though the period in question is still classified as the Iron Age. Importantly, however, such validation tools could safeguard against human error, when inputting data could potentially violate broader chronologies.

In such cases, by validating the data, detected errors can be reported to the database owner. Some error types might be easy to fix, even with an automated process, whereas other error types need human consideration; here, a semi-automatic workflow could be utilised. In such a scenario, a domain specialist can be given a list of errors and suggestions for fixing them (e.g., a 'from date' later than 'to date' might be corrected by swapping the dates). Such errors that were found in the case study could have been prevented already in the data recording phase by utilising validation mechanisms when inputting the data, including disallowing the user to add conflicting dates in the first place.

5 CONCLUSION

This paper aims to show the impact of human decision-making on the research value of archaeological data, but also the limitations of data management tools and – by considering these aspects together – the overall complexities of ensuring high-quality data in archaeological datasets, here taking the PAS database as an example.

It has shown that controlled vocabularies (such as thesauri, ontologies, etc) are essential tools for enhancing data quality, not only when inputting data, but also for improving precision and recall when mining or searching databases. As such, it is imperative that recorders use terms from a predetermined list of 'drop-downs' for key data

[33] FISH thesauri: https://www.heritage-standards.org.uk

following industry-agreed vocabularies; in general terms, the PAS database follows FISH vocabularies, though it has 'flattened' the FISH thesaurus (i.e. its hierarchy is not respected in the 'object-type' drop-down and even new terms have been added). That aside, if these principles are followed, it is theoretically straightforward for recorders to choose the correct terms to 'describe' the items they record. Using an agreed vocabulary also means that researchers and other end users can refer to this to understand these terms and their relationship to one another. In short, controlled vocabularies (when used effectively) make it easier for end users to search for specific items and/or download data without speculating about every possible term for an item (or its attribute) that the recorder might have used.

Besides the work needed by developers to implement controlled vocabularies (versus free text entry) within a database, there is the issue of recorders then failing to use them properly. The case studies above show how drop-downs can be used differently by multiple users, even in the case where fields are mandatory, thus highlighting the need for continued training alongside the use of a controlled vocabulary. This differing usage is sometimes likely to reflect the fundamental epistemological issue that controlled vocabularies, like all KOS, are imperfect at modelling the real world and certainly cannot be taken as neutral representations of it (e.g., [10]). Highlighted above, concerning pilgrim and other badges, was the issue of how recorders might distinguish between the religious and secular, based not only on their understanding of material culture but also on how such theoretical concepts fit within the medieval worldview. This might be a particular issue for archaeology and cultural heritage studies, subjects that deal with highly complex contingent phenomena and processes where our understanding and research are continually evolving. Variance in the 'real world' application of a KOS (here expressed in the use of drop-downs to record material culture) is therefore also impacted by the human need to adapt a model to user needs and understandings that might change over time. Indeed, the PAS database has evolved much since its original inception and delivery in 2003 [29].

Clearly, and of fundamental importance, using controlled vocabularies is not enough to solve all the potential issues human decision-making can bring to a database. Recorders can still end up using different terms through personal choice, either because there are quirks in the controlled vocabulary, the options given do not seem appropriate for those inputting data, or recorders lack knowledge or training, or simply through basic error, laziness or incompetence. Here, it is also essential to note that those inputting data might not be using the data themselves, and therefore might not fully appreciate the nuances of the decisions they make – such as to record 'completeness' or 'surface treatment', for example. With PAS numismatic data, as a case in point, it is clear that some attributes of a coin are valued less by some recorders than others, even when a drop-down or choice of another field exists. It is likely, that this is due to the time they have to record these items – especially with the growth of metal-detecting and the pressures this puts on those recording such items [23]. Invariably where data is missing these attributes are unavailable in any search, impacting the dataset's overall value.

Focusing on recording particular information over other sorts of data can also lead to biases in the data, as shown above. Sections of the PAS database (like many long-standing cultural heritage datasets) have been subject to different data production processes: some even originate from external data dumps (such as the inclusion of the CCI and IARCW datasets) and the intense recording of certain object types (for instance Roman 'grots'). Also apparent in the PAS database are differences in recording practices from one area to another. An example might be whether more common items are photographed or not – typically less likely in East Anglia, with the primary motivation to increase recording capacity. Less obvious to the researcher, might be the omission of data that is seen as less important in a given recording context, such as 'method of manufacture', or even usually common attributes like 'weight'. When such data is missing, the archaeological record is less complete and, as such, harder to study across larger geographic areas in a meaningful way. Even less easy to detect, and requiring either deep (and therefore not easily replicated) knowledge of the long history of the database, or extensive computational data exploration, are hidden particulars such as those linked to how spatial precision has been recorded. This is an important point, highlighting not only the need for database owners to log aspects of development (noted above), but also how the dataset has been collated and curated, and the decisions behind those choices.

Minor reworking of used vocabularies might help recorders produce better data, but in practice, this can be difficult to manage retrospectively – especially if thousands of finds would need to be re-classified. Faceted search of data can help reveal disparities in data by showing the hit counts for different selections. It is then easy to see, for example, if there are many more 'badges' compared to 'pilgrim badges' recorded in a certain county compared to others, which might indicate either an issue with recording practices (or even reveal) an interesting research question. The ability to easily visualize the data in various ways could also be helpful. PAS system currently offers faceted search to the users, however visualization options are limited. The drawback of faceted search is that the selections still need to be chosen manually and issues are found by comparing numbers. With current and future AI technology it might be possible to monitor relative hit counts for different selections in the data and alert the users of possible issues in the data where, for example, one object type from one period might be over or under-represented in the data of one county (or larger area) compared to others. Regarding data inconsistencies that can be defined as violations of explicit integrity constraints (e.g., 'from date' cannot be later than 'to date'), data validation methods such as the shape-based SHACL (as previously demonstrated in this paper) already provide possibilities for detecting such errors when inputting data into a database.

This paper advocates for database developers to work as closely as possible (as surely most do) with recorders and other primary users, but also to have a more holistic view of the needs of other potential end users, including those who might use the data in other contexts. The latter is trickier to account for, as it is harder to predict who these others might be and also justify the additional resources needed for such an approach; though there is a trajectory in the field of digital humanities to be more open-minded in this regard. Crucial, from an end-user perspective, is being transparent in what controlled vocabularies are used, how they are implemented and how data is constructed. It is the nature of the PAS database, like with other datasets, that those closest to it best appreciate how to mine it for the questions they wish to answer. In some ways this is inevitable, so therefore end users must have the information they need (in terms of how a dataset is created and data inputted) to fully appreciate its biases and make as full use as possible of it for their research.

ACKNOWLEDGMENTS

This research has received funding from the Jenny and Antti Wihuri Foundation, and the European Union's Horizon 2020 research and innovation programme under the Marie Sklodowska-Curie grant agreement No 896044. The authors are grateful to the University of Helsinki and the Institute for Social Sciences and Humanities (HSSH) for supporting Michael Lewis as HSSH Visiting Professor in 2023 and 2024, and for funding a 2021 pilot project that led to the development of the PASampo. This article is an outcome of that support to foster research collaborations at and beyond the university. Thanks to the Finnish Cultural Foundation for an Eminentia grant for Eero Hyvönen. CSC – IT Center for Science has provided computational resources for our work.

REFERENCES

[1] Ron Artstein. 2017. Inter-annotator agreement. In *Handbook of linguistic annotation*, Nancy Ide and James Pustejovsky (Eds.). Springer Netherlands, Dordrecht, 297–313. https://doi.org/10.1007/978-94-024-0881-2_11

[2] Andrew Bevan. 2012. Spatial methods for analysing large-scale artefact inventories. *Antiquity* 86 (2012), 492–506. https://doi.org/10.1017/S0003598X0006289X

[3] Roger Bland. 2005. A pragmatic approach to the problem of portable antiquities: The experience of England and Wales. *Antiquity* 79 (2005), 440–447. https://doi.org/10.1017/S0003598X00114218

[4] Andrew Brown and Sam Moorhead. 2021. The Roman coins from Exeter and its hinterland. In *Studies in the Roman and medieval archaeology of Exeter: Exeter, a place in time. Volume II*, Stephen Rippon and Neil Holbrook (Eds.). Oxbow Books, Oxford, 435–460. https://doi.org/10.2307/j.ctv2npq9kz.29

[5] Adam Daubney. 2016. *Portable antiquities, palimpsests, and persistent places: A multi-period approach to Portable Antiquities Scheme data in Lincolnshire.* Sidestone Press, Leiden.
[6] Pieterjan Deckers, Michael Lewis, and Suzie Thomas (Eds.). 2016. *Aspects of non-professional metal detecting in Europe.* De Gruyter. Topical Issue of Open Archaeology.
[7] Lisa Fenucci. forthcoming 2026. Sexual badges and their unique visual culture: the perspective of the late medieval Low Countries on sexuality. In *A United Europe of Things 2*, Michael Lewis, Jakub Sawicki, and Maria Vargha (Eds.). Yellow Point, Wroclaw.
[8] Mark Gillings, Piraye Hacigüzeller, and Gary Lock. 2020. *Archaeological spatial analysis: A methodological guide.* Routledge, Abingdon and New York.
[9] Chris Gosden, Chris Green, Anwen Cooper, Miranda Creswell, Victoria Donnelly, Tyler Franconi, Roger Glyde, Zena Kamash, Sarah Mallet, Laura Morley, Daniel Stansbie, and Letty ten Harkel. 2021. *English landscape and identities.* Oxford University Press.
[10] Birger Hjørland. 2008. Semantics and knowledge organization. *Annual Review of Information Science and Technology* 41:1 (2008), 367–405. https://doi.org/10.1002/aris.2007.1440410115
[11] Jacob Holland-Lulewicz. 2021. From categories to connections in the archaeology of eastern North America. *Journal of Archaeological Research* 29 (2021), 537–579. https://doi.org/10.1007/s10814-020-09154-w
[12] Tomi Kauppinen, Glauco Mantegari, Panu Paakkarinen, Heini Kuittinen, Eero Hyvönen, and Stefania Bandini. 2010. Determining relevance of imprecise temporal intervals for cultural heritage information retrieval. *International Journal of Human-Computer Studies* 86, 9 (2010), 549–560.
[13] Richard Kelleher. 2017. Pilgrims, pennies and the ploughzone. Folded coins in medieval Brittany. In *Divina moneta. Coins in religion and ritual*, Nanouschka Myrberg Burström and Gitte Tarnow Ingvardson (Eds.). Routledge, London, 68–86.
[14] Fleur Kemmers and Nanouschka Myrberg. 2011. Rethinking numismatics. The archaeology of coins. *Archaeological Dialogues* 18 (1) (2011), 87–108.
[15] Daniel Kless, Simon Milton, and Edmund Kazmierczak. 2012. Relationships and relata in ontologies and thesauri: Differences and similarities. *Applied Ontology* 7, 4 (2012), 401–428.
[16] Jose Emilio Labra Gayo, Eric Prud'hommeaux, Iovka Boneva, and Dimitris Kontokostas. 2017. *Validating RDF Data.* Synthesis Lectures on the Semantic Web: Theory and Technology, Vol. 7. Morgan & Claypool Publishers LLC. https://doi.org/10.2200/s00786ed1v01y201707wbe016
[17] Michael Lewis. 2009. *The Portable Antiquities Scheme annual report 2007.* British Museum, London.
[18] Michael Lewis. 2013. Pilgrim signs of St Margaret of Antioch: Some thoughts on their spatial distribution. *Medieval Archaeology* 57 (2013), 280–283.
[19] Michael Lewis. 2014. *Saints and their badges: Saints' lives and medieval pilgrim badges.* Greenlight Publishing, Witham.
[20] Michael Lewis. 2016. A detectorist's utopia? Archaeology and Metal-Detecting in England and Wales. *Open Archaeology* 2 (2016), 126–139.
[21] Michael Lewis. 2023. *The Portable Antiquities Scheme annual report 2022.* British Museum, London.
[22] Michael Lewis. forthcoming. Pinning down St George: Characterising pilgrim badges of St George.
[23] Michael Lewis, Frida Ehrnsten, Tuuli Kurisoo, Eljas Oksanen, and Ville Rohiola. forthcoming. Finds reporting to finds recording: Opportunities provided by digital technology and citizen science in the processing of public finds in England, Estonia and Finland. *European Journal of Archaeology* (forthcoming).
[24] Frances McIntosh and Sam Moorhead. 2012. Roman quadrantes found in Britain, in light of recent discoveries recorded with the Portable Antiquities Scheme. *British Numismatic Journal* 81 (2012), 223–9.
[25] Sam Moorhead. 2013. *A history of Roman coinage in Britain.* Greenlight Publishing, Witham.
[26] Martin Newman. 2011. The database as material culture. *Internet Archaeology* 29 (2011). https://doi.org/10.11141/ia.29.5
[27] Eljas Oksanen and Michael Lewis. 2023. Evaluating transformations in small metal finds following the Black Death. *Medieval Archaeology* 67.1 (2023), 159–186.
[28] Eljas Oksanen, Heikki Rantala, Jouni Tuominen, Michael Lewis, David Wigg-Wolf, Frida Ehrnsten, and Eero Hyvönen. 2022. Digital humanities solutions for pan-European numismatic and archaeological heritage based on linked open data. In *DHNB 2022. The 6th Digital Humanities in the Nordic and Baltic Countries Conference 2022.* CEUR Workshop Proceedings, Vol. 3232, 353–361. https://ceur-ws.org/Vol-3232/paper34.pdf
[29] Dan Pett. 2010. The Portable Antiquities Scheme's database: Its development for research since 1998. In *A decade of discovery: Proceedings of the Portable Antiquities Scheme conference 2007*, Sally Worrell, Geoff Egan, John Naylor, Kevin Leahy, and Michael Lewis (Eds.). BAR Publishing, Oxford. https://doi.org/10.30861/9781407307237
[30] Richard Reece. 1987. *Coinage in Roman Britain.* Seaby.
[31] Richard Reece. 1995. Site-finds in Roman Britain. *Britannia* 26 (1995), 179–206. https://doi.org/10.2307/526876
[32] K. Robbins. 2012. *Understanding the Impact of Sampling Bias Data Recorded by the Portable Antiquities Scheme.* Ph. D. Dissertation. University of Southampton.

[33] Katherine Robbins. 2014. Balancing the scales: Exploring the variable effects of collection bias on data collected by the Portable Antiquities Scheme. *Landscapes* 14 (2014), 54–72.
[34] Jakub Sawicki, Michael Lewis, and Maria Vargha. 2024. *A united Europe of things: Portable material culture across Europe.* Springer.
[35] J. David Schloen. 2001. Archaeological data models and web publication using XML. *Computers and the Humanities* 35, 2 (2001), 123–152. http://www.jstor.org/stable/30204847
[36] Monica L. Smith. 2014. Citizen science in archaeology. *American Antiquity* 79, 4 (2014), 749–762. http://www.jstor.org/stable/43184948
[37] Brian Spencer. 1998. *Pilgrim souvenirs and secular badges: Medieval finds from excavations in London.* The Stationery Office, London.
[38] Suzie Thomas. 2012. How STOP started: Early approaches to the metal detecting community by archaeologists and others. In *Community archaeology: Themes, methods and practices*, Gabriel Moshenska and Sarah Dhanjal (Eds.). Oxbow Books, Oxford & Oakville, 42–57.
[39] Philippa Walton. 2012. *Rethinking Roman Britain: Coinage and archaeology.* Moneta, Wetteren.
[40] Philippa Walton and Sam Moorhead. 2016. Coinage and collapse? The contribution of numismatic data to understanding the end of Roman Britain. *Internet Archaeology* 41 (2016). https://doi.org/10.11141/ia.41.8
[41] Anna Wessman and Eljas Oksanen. 2022. Metal-detecting data as citizen science archaeology. In *Odes to Mika. Professor Mika Lavento's Festschrift as he turns 60 years old.*, V. Halinen, P. Heyd and K. Mannermaa (Eds.). The Archaeological Society of Finland, 293–302.
[42] Anna Wessman, Suzie Thomas, Ville Rohiola, Jutta Kuitunen, Esko Ikkala, Jouni Tuominen, Mikko Koho, and Eero Hyvönen. 2019. A citizen science approach to archaeology: Finnish archaeological finds recording linked open database (SuALT). In *DHN 2019. Digital Humanities in the Nordic Countries.* CEUR Workshop Proceedings, Vol. 2364. https://ceur-ws.org/Vol-2364/43_paper.pdf
[43] Mark D. Wilkinson, Michel Dumontier, Ijsbrand Jan Aalbersberg, Gabrielle Appleton, Myles Axton, Arie Baak, Niklas Blomberg, Jan-Willem Boiten, Luiz Bonino da Silva Santos, Philip E. Bourne, Jildau Bouwman, Anthony J. Brookes, Tim Clark, Mercè Crosas, Ingrid Dillo, Oliver Dumon, Scott Edmunds, Chris T. Evelo, Richard Finkers, Alejandra Gonzalez-Beltran, Alasdair J.G. Gray, Paul Groth, Carole Goble, Jeffrey S. Grethe, Japp Heringa, Peter A.C. 't Hoen, Rob Hooft, Tobia Kuhn, Joost Kok Ruben Kok, Scott J. Lusher, Maryann E. Martone, Albert Mons, Abel Packer, Bengt Persson, Philippe Rocca-Serra, Marco Roos, Rene van Schaik, Susanna-Assunta Sansone, Erik Schultes, Thierry Sengstag, Ted Slater, George Strawn, Morris A. Swertz, Mark Thompson, Johan van der Lei, Erik van Mulligen, Jan Velterop, Andra Waagmeester, Peter Wittenburg, Katherine Wolstencroft, Jun Zhao, and Barend Mons. 2016. The FAIR guiding principles for scientific data management and stewardship. *Scientific Data* 3 (2016). https://doi.org/10.1038/sdata.2016.18
[44] Marcia Zeng and Jian Qin. 2022. *Metadata, third edition.* ALA Neal-Schuman, Chicago.
[45] Marcia Lei Zeng and Philipp Mayr. 2019. Knowledge Organization Systems (KOS) in the semantic web: A multi-dimensional review. *International Journal of Digital Libraries* 20 (2019), 209–230. https://doi.org/10.1007/s00799-018-0241-2