Semantic Solutions for Democratizing Archaeological and Numismatic Data Analysis

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Museums, heritage agencies and other institutions responsible for managing archaeological cultural heritage across Europe are engaged in developing digital platforms to better open their collections to the public as a common resource for the purposes of discovering, learning about, and sharing our common past. This paper explores the potential of new semantic computing technologies in democratizing not only public access to digital cultural heritage records, but also to computational and Linked Open Data -assisted data analysis and knowledge discovery. As a case study, we consider archaeological and numismatic Open Data services in Finland, and discuss the research results obtained during the ongoing development work for the CoinSampo framework for opening Finnish and international numismatic data. Existing digital cultural heritage services are often built with the needs of professional collections management in mind. The presentation of the records is typically structured after the familiar format established for the printed catalogues of yesteryear, with few analytical tools that would take advantage of the potential of digital data to probe and visualize internal relationships and patterns within the full body of the opened material. CoinSampo, however, will provide scientific tools to new audiences among the non-professional public who have not enjoyed such a level of access to numismatic data. The broad range of target audiences we envisage includes collections managers, who will benefit from enhanced access to their own data for updating records and for error detection and correction, as well as academic researchers interested in using the material in scientific analysis. Importantly, it also includes non-professional groups such as coin collectors, educators, local historians, and the archaeological hobby metal-detectorists who produce most of the new coin finds entering the national collections in Finland and in other European countries where detecting is legal. By adopting a citizen science and participatory heritage approach in the development of Open Data services, we aim to promote a technological model for cultural heritage dissemination that addresses the needs of a wide spectrum of different user audiences inside and outside the professional sphere.

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

Additional Key Words and Phrases: numismatics, semantic web, Linked Open Data, archaeology, collections management, data analysis, digital humanities

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1 INTRODUCTION

The previous decade has witnessed a proliferation in the number of archaeological finds being made by the public across Europe, mainly through hobby metal-detecting. This is especially so in several north-west European countries where this activity is permitted, albeit with restrictions. In these countries, including Finland, national cultural heritage schemes have been set up to record and to open the material, generating an enormous amount of data that is of great value to archaeology [10]. In many instances our understanding of several common object types – including coins, dress accessories and domestic items such as spindle whorls – and thereby of the social, cultural, economic or political processes and phenomena that are linked to their production and use, are being revised (see Figure 1) [29, 30, 33, 34, 46]. Crucially, by maintaining online platforms that present key data about these finds (archaeological descriptions, weights and measurements, images, findspot information, etc.) European public finds recording schemes, and other heritage institutions managing find records, have created a significant and growing reservoir of cultural heritage data that can be used equally by professionals and by members of the public (including metal-detectorists) interested in archaeology. For responsible detectorists, these digital services can play a central role in advancing the democratization of archaeological science – in particular for those who have a serious or avocational relationship with the activity and might be described as 'citizen science archaeologists' [15, 51, 53].

In this paper we discuss and respond to a set of new large-scale needs in cultural heritage management, research and dissemination created by these developments, focusing on the democratization of data and knowledge production through powerful but highly accessible public data analytical tools and services. Based on our ongoing research and experience in developing new online services for the **Finnish Heritage Agency's (FHA)** archaeological and numismatic collections, we propose a paradigm shift in opening cultural heritage data [38, 41].[1]

The vast majority of public cultural heritage services open their material in a manner modelled after the traditional printed catalogue: record entry by record entry, archaeological object by archaeological object. In CoinSampo, our model cultural heritage demonstrator for Finnish numismatic data, users are able to easily explore, visualize and examine larger patterns and structures within the data through integrated semantic search-and-analysis tools. By taking an approach that considers the data as a complete entity from the start, this model empowers users to build new statistical, geographical, temporal and networked perspectives on past societies and historical phenomena as arising from a holistic body of interconnected material.

We present the current results of the intersectoral and interdisciplinary (archaeology, computer sciences, cultural heritage, digital humanities, museology and numismatics) project ***DigiNUMA: Digital Solutions for European Numismatic Heritage***,[2] conducted at the University of Helsinki and Aalto University in collaboration with the FHA and the National Museum of Finland. Our core research aim is to advance the development of open digital heritage services, approaching it from multiple interlinked directions. These are: (a) to produce new ontological infrastructure for improving the recording process and quality of public finds data in Finland, with specific reference to international cultural heritage data harmonization; (b) to test and interpret the data through Digital Humanities analyses; and (c) to develop the pilot online data and public access heritage service demonstrator CoinSampo [41] (*Rahasampo* in Finnish), based on the Sampo model of cultural heritage data services

[1]This article contains material previously published in these conference papers.
[2]DigiNUMA project homepage: https://seco.cs.aalto.fi/projects/diginuma/

Fig. 1. The amount of new numismatic data in Finland has increased significantly in the last decade, creating a need for a revision of the scholarship. In the picture is a rare example of a medieval coin minted in Finland: an Abo type coin minted in Turku during the reign of Erik of Pomerania (*c.* 1410–1420). Only one coin of this type was known until 2017, when a metal-detectorist found this specimen in a field in Häme, Finland. Since then, one more fragment of this coin, minted with different dies, has been found, showing that it was not so unique after all. National Museum of Finland, RK 2017006:1. Photo: Jani Oravisjärvi/National Museum of Finland.

[24], with built-in apps for creating data analysis and visualizations as a model for disseminating archaeological data within an international context. The search and visualization tools of the web application open the data for researchers, but perhaps more importantly also to the wider public, in a way that makes visualizing and analysing the data easy.

CoinSampo extends the FindSampo [25, 40] (*Löytösampo* in Finnish) framework developed in the Academy of Finland funded consortium project *Finnish Archaeological Finds Recording Linked Open Database* (*SuALT*, 2017–2021),[3] which was launched in late 2021 for sharing metal-detected finds data collected by the FHA.[4] The planned date for opening the data and the CoinSampo portal to the public is at the end of 2023, and the FindSampo demonstrator is already available. What differentiates the CoinSampo from the FindSampo is the opened data (specific focus on numismatic collections), a larger selection of analytical tools and an enhanced Linked Open Data capability through more formally defined numismatic entities and concepts.

The following discussion is based on the lessons learned during the *DigiNUMA* and *SuALT* research projects. Novel semantic applications contribute to advancing social good by making digitized archaeological heritage more accessible, but developers must be aware of the needs of the target communities. The diverse user audiences that CoinSampo is intended to serve include, in addition to heritage professionals and academic scholars, numismatists, metal-detectorists and other public finders, local historians, and amateur archaeologists. The model heritage data service demonstrator can equally be used for educational purposes in schools and universities. We thereby aim to contribute to the broader conversation about how recent digital transformations have affected knowledge creation and exchanges between actors and stake-holders in the field of archaeological and numismatic cultural heritage: how can we not only better open data to a broad variety of audiences but also democratize the capacity for its exploration, visualization and analysis, enhancing everyone's ownership of our shared past.

[3]Project homepage: https://seco.cs.aalto.fi/projects/sualt/
[4]The FindSampo portal online: https://findsampo.fi

2 RELATED WORK

As noted, the specific research context of this paper is provided by European portable archaeological metalwork finds and the participatory heritage activity by which they have largely been recovered. Legal conditions and professional attitudes towards the metal-detecting hobby vary across Europe [10]. But, notwithstanding many issues related to resourcing in heritage management, challenges in dealing with the increasing number of reported finds and in safeguarding vulnerable archaeology [31], there is increasing attention paid to the added value of a permissive approach in terms of scientific knowledge and the societal impact of public participation. In those countries where finds recording schemes exist, there has been an unprecedented increase in 'big data' and public engagement with archaeology [11, 13, 27]. The scope for reaching out to involve the public in archaeological knowledge generation is considerable: the longest running of the European public finds schemes, the **Portable Antiquities Scheme in England and Wales (PAS)** at the British Museum and Museum of Wales,[5] contains over 1 million records of over 1.6 million objects reported since 1997 [4, 32].

Following the pioneering work of the PAS, the last ten years have seen several public finds recording schemes established as a matter of national-level significance for cultural heritage management. This includes Finland (FHA, *Ilppari*[6] and FindSampo[7]), Belgium (MEDEA[8]), the Czech Republic,[9] Denmark (Digitale Metaldetektorfund, DIME[10]) and the Netherlands (Portable Antiquities of the Netherlands, PAN[11]). Recording schemes are also being developed in several other countries, including Estonia[12] and Norway [1, 2, 5, 11, 28, 32, 53]. Besides reaching out to the public to record the finds they make, which in some cases is mandatory,[13] these schemes inform the public of the laws and guidelines related to metal-detecting and other public searching[14] (especially encouraging responsible behaviour), and assist law enforcement in response to illegal metal-detecting, damage to historic monuments, and the failure to report certain categories of finds [8].

In Finland, the watershed moment for archaeological hobby metal-detecting took place in the mid-2010s [44, 52]. Here, as elsewhere in northern Europe where population densities have been historically lower than in the south, the absolute numbers of recorded finds are also smaller. But their relative growth since metal-detecting became popular is significant; between 2000 and 2010 there were some 400 finds made by members of the public recorded in the *Muinaiskalupäiväkirja*,[15] the diarization system of the FHA's archaeological collections. Between June 2015 (when finds began to be entered into a new archaeological finds database using the *Luettelointisovellus* application) and September 2017 some 3,000 new public finds – almost all metal-detected – were recorded [52]. Some 1,700 to 2,000 new metal-detected finds are now taken into the collections and recorded per annum.[16] A challenging sea-change has taken place in the course of just a couple of years, with heritage infrastructure, human resources and established management workflows struggling to keep up with the new demands created.

Much as in other European countries, in Finland a number of technological solutions have been developed in response to this changing public cultural heritage management environment. Finnish institutions were, after

[5] https://finds.org.uk
[6] https://www.kyppi.fi/palveluikkuna/ilmoitus/edit/asp/enk_default.aspx
[7] https://findsampo.fi/en
[8] https://vondsten.be
[9] https://amcr-info.aiscr.cz/?page=pas
[10] https://www.metaldetektorfund.dk
[11] https://portable-antiquities.nl
[12] https://leiuatlas.ee
[13] According to Finnish law all finds older than 100 years must be reported: Antiquities Act 295/1963 https://www.finlex.fi/fi/laki/ajantasa/1963/19630295#a295-1963
[14] See, e.g., for England and Wales: https://finds.org.uk/documents/file/Code-2017.pdf and for Finland https://www.museovirasto.fi/uploads/Arkisto-ja-kokoelmapalvelut/Julkaisut/muinaisjaannokset-ja-metallinetsin-2017.pdf
[15] https://www.kyppi.fi/palveluikkuna/kmloyto
[16] 2015-2017 records are opened by the FindSampo demonstrator at https://loytosampo.fi/en/. Later records are not yet available. Data: FHA and Ilppari.

all, early adopters in making cultural heritage data services available online. Since 2010, FHA's *Muinaisjäännösrekisteri* database of archaeological monuments has published historic environment data as a free GIS service and today contains information and linked records on over 50,000 archaeological sites across the country.[17] *Luettelointisovellus* was originally developed as an administrative tool for recording archival information for all archaeological object finds taken into the national collections. In response to the metal-detecting boom, in 2019 the Agency launched *Ilppari*, an online service for members of the public to easily report data on amateur archaeological finds and observations [45]. *Muinaisjäännösrekisteri* also has a category for sites of stray finds, and if the find site for an artefact is later recognized as an archaeological monuments site (e.g., a cemetery or a settlement), the find will be linked to the relevant record. *Luettelointisovellus* has been replaced by the newer application *Apuri* in 2023, facilitating the transference of information between *Ilppari*, *Muinaiskalupäiväkirja* and *Muinaisjäännösrekisteri*.

The data service environment for recording Finnish archaeology is therefore rather complex, and sites and stray finds fundamentally remain two different data categories. A situation has therefore developed where the regularly updated monument and site data is open and easily accessible by a system managed in-house by the FHA (*Muinaisjäännösrekisteri*), but the artefact finds data is processed by various different systems. *Luettelointisolvellus*, *Ilppari* and *Apuri* were primarily designed to support various administrative processes in the management of stray finds, and up-to-date finds data is not yet directly opened to the public [45]. In order to improve and modernize the FHA's internal data services for collections management – including handling reported finds and archaeological artefacts – various legacy catalogues and collections-specific databases are in the process of being consolidated into the national collections management system MuseumPlus.[18]

Arriving from a collections management paradigm (e.g., keeping track of where a given object is physically located in the archives), MuseumPlus, however, was not designed with scientific archaeological information, such as including finds coordinate location, in mind. Furthermore, data from MuseumPlus is opened through the national Finna[19] search service and through it fed into the European cultural heritage cloud Europeana.[20] Finna is developed and maintained by the National Library of Finland, in collaboration with Finnish memory organisations, and its data model is even further removed from the needs of archaeological cultural heritage. Objects in these services are designed to be examined as individual records, not as an integrated body of material. Moreover, all the information is in Finnish and as the development of, for example, numismatic ontologies is ongoing, it is not straightforward to enrich the data through **Linked Open Data (LOD)** principles by linking the published material to other existing international sources with fixed object classifications. Finding a solution that serves both the FHA's collections management needs and also provides an Open Data and Open Cultural Heritage service is one of the major challenges in Finnish digital cultural heritage management [45]. These problems are not, of course, very different from experiences in many other European countries, where various legacy systems and data services across diverse cultural sectors have been brought together into complicated patchwork ecosystems (see, e.g., in the UK [6]).

Furthermore, an ongoing challenge for national digital heritage services is connecting specific datasets to wider bodies of knowledge. The traditional organization of archaeological cultural heritage is deeply rooted in an epistemological foundation of typologies and taxonomies that primarily define, organize, understand and give it relevance as a bounded phenomenon occurring within the confines of modern polities and communities (e.g., a point recently raised in [21]). The application of LOD solutions holds the promise of enriching disparate datasets through mapping of concepts (object types, defined periodizations and other properties) to shared international resources. This requires considerable data harmonization and ontological research that is

[17] https://www.kyppi.fi/palveluikkuna/mjreki
[18] https://museoliitto.fi/kookos/
[19] https://finna.fi
[20] https://europeana.eu

beyond any single project. We therefore collaborate with other pan-European LOD harmonization projects such as ARIADNEplus[21] (all archaeological data [42]), tying in with the aims and objectives of the European Public Finds Recording Network [12][22] to enhance the possibilities for transnational research of metal-detected and other public archaeological finds. Especially interesting for the project is the international numismatic network Nomisma.org[23] [17, 48, 54]) started by the **American Numismatic Society (ANS)** in 2010. The Nomisma.org project aims to facilitate the presentation of numismatic concepts using LOD. As of December 2022, more than 50 different institutions have provided datasets totalling nearly 370,000 coins for the project. The classes and properties of the Nomisma.org ontology aim to cover all aspects necessary for the description of coins. Currently, Nomisma.org is populated mainly with instances related to the classical era, but work is ongoing to extend the range of concepts to cover the medieval and eventually the Early Modern and modern periods.

3 METHODS: DESIGN SCIENCE AND THE SAMPO MODEL

The general methodology of our research is mainly inspired by the paradigm of design science [20, 39]. Design science aims to solve important problems in innovative ways by building artifacts, and by evaluating those artifacts. The created artifacts can be software systems, but also models and methods. The process of design science is iterative. It consists of defining a motivating problem, and then developing, demonstrating and evaluating the artifact intended to help in solving the problem. Finally the the results must be communicated to the appropriate audience in a manner that is understandable and relevant to them. In our case the artifacts include the CoinSampo application, the various ontologies used to represent the data, and a model for new ways of publishing archaeological cultural heritage data in an accessible manner.

In our work we apply the 'Sampo model' [24], which is a model for publishing cultural heritage LOD in a collaborative way. It has been developed over twenty years at Aalto University and the University of Helsinki by the Semantic Computing Research Group.[24] The model has been developed through practical experiences on working on numerous projects and some twenty online Sampo systems[25] where cultural heritage is published on the Semantic Web.[26]

In the Sampo model the process of creating and publishing data is based on applying the Semantic Web and Linked Data principles [19] to address the problems of semantic data interoperability and distributed content creation at the same time. The use of shared or interconnected ontologies,[27] or vocabularies of terms, makes comparing data from different sources easier. Ideally this makes the creation of data simpler, as there is no need to redefine all the necessary terms and their connections for every new project. Using the **Resource Description Framework (RDF)**[28] format the data is published as a Linked Data knowledge graph, as openly as possible subject to restrictions such as GDPR[29] and other legislation regarding sensitive data. The data is served from an open triplestore database that can be accessed through a SPARQL endpoint.[30] A Sampo web application queries this same endpoint. Users can access the queries used by the application through a view in the application, and use those as a basis to start creating their own queries. Furthermore, the web application will also offer an easy way to download the data in, for example, CSV format, enabling the data to be further interrogated by users

[21] https://ariadne-infrastructure.eu
[22] https://www.helsinki.fi/en/networks/european-public-finds-recording-network
[23] http://nomisma.org
[24] The name 'Sampo' comes from the Finnish epic Kalevala: it refers to a mythical artefact and can be read as a metaphor for ancient technology that brings wealth and fortune to its owner.
[25] Sampo portals homepage: https://seco.cs.aalto.fi/applications/sampo
[26] https://www.w3.org/standards/semanticweb/
[27] https://www.w3.org/standards/semanticweb/ontology
[28] https://www.w3.org/RDF/
[29] https://gdpr.eu
[30] https://www.w3.org/TR/sparql-query/

proficient in specialist software. A model data service and semantic portal will be described more in detail below using the CoinSampo example.

A key aim has been to "standardize" the user interface logic and the creation of applications where possible. This makes it easier for users to learn to use new systems, and also makes it easier to create new applications for data analysis and visualization. Technologically, we use the Sampo-UI [26] framework as the basis of our web user interface. This allows us to reuse many tools that have been implemented for other portals with minor changes, while also making it easy to reuse tools specifically implemented for CoinSampo in future projects. Furthermore, the Sampo model calls for separating the data service from the user interface. Data is by its nature more permanent than the web applications that are used to access it. A web application will often become obsolete in only a couple of years. In contrast the data, if well structured and made, is reusable for much longer. Researchers can therefore maintain access longer to the original data service if they have the necessary skills, and new more up-to-date applications can be build to open the data by software engineers.

As discussed, a major question of relevance to cultural heritage management at an international level is how to open data with a complex institutional and operational background in a manner that is sustainable, satisfies the needs of its primary producers and administrative users in museums and agencies, and offers new possibilities for researchers and more casual users in appreciating heritage material across a broad spectrum of analyses. Based on our research, we propose the Sampo model as a solution, one that would not necessarily replace all existing dedicated collections management tools but would consolidate powerful new instruments for opening, assessing and investigating data.

4 RESEARCH DATA

The archaeological cultural heritage recovered and reported by public finders forms a complex and diverse body of material. Therefore, as a case study, we specifically target coin finds obtained from Finnish and international digital archives. Numismatic data is singularly suitable for humanities as well as semantic computing research into digital cultural heritage, because: (a) Coins are by far the most numerous object-type reported by the members of the public to the national finds recording schemes (e.g., [29, 36]); (b) coins are of great interest to most metal-detectorists and other finders as easily recognizable historical objects, which in significant part accounts for this positive bias [36, 43]; (c) there is a strong basis in numismatic scholarship for new data exploration and ontological work (e.g., in England [35] and in Finland [14, 47]), as well as the ontological foundation provided in Finland by the MAO/TAO[31] ontology and internationally through Nomisma.org; (d) the data is often precise in terms of its dating and place of production, making it suitable for Digital Humanities analysis; and (e) coins move across borders, recording and reflecting historical exchanges that are relevant to wider European audiences. In short, the interconnected nature of numismatics makes it an excellent testing ground for semantic research based on novel data visualization and LOD applications [22].

What public finds material is recorded varies from country to country. In Finland, the FHA's archaeological database contains full records of only those objects that have been taken into the national collections. In practice all objects that are pre-historic or medieval (older than *c.* AD 1560) are claimed, whereas Early Modern (after *c.* AD 1560) finds are claimed only if the object is of particular archaeological importance or interest. The great majority are returned to the finder. But while from a collections perspective large quantities of, for example, Early Modern coins are less valued, since 2014 there has been a concentrated drive at the numismatic collections to record all pre-20th century coins reported by finders in a separate numismatic database. This has built up a dataset that serves multiple purposes: in northern European terms it forms an unusually comprehensive data sample that can be deployed in *longue durée* numismatic research, and it also provides a heritage management resource for tracking hobby detectorist activity geographically. This provides a more comprehensive picture of where people detect, even if the finds they recover are not taken into collections and therefore do not end up

[31] MAO/TAO - Ontology for Museum Domain and Applied Arts is available at https://finto.fi/maotao/en/. Note that this is a SKOS vocabulary.

in the main national archaeological database. The dataset currently stands at over 16,000 records of single coin finds and, together with other smaller datasets such as the ongoing digitization of Viking Age coin hoard finds, forms the core of the Finnish research material for developing the CoinSampo data service.

To ensure the compatibility of our data model outside the national context we use the following international data providers. The PAS contains over 500,000 coin records from the British Iron Age (800 BC to AD 42) to the modern period. Generated by public finders and therefore yielding insights into the same process and selection biases that underlie the Finnish data, it is also one of the largest numismatic databases in the world and highly suitable for testing applications in archaeological 'big data' analysis [3, 7]. As noted, the transnational numismatic data harmonization project Nomisma.org has opened a number of datasets sharing an ontological framework and a data model, one which has been developed specifically to provide a semantic foundation for linking and combining data arriving from diverse collections and institutional sources [17, 48]. Using the large and complex data from the British Museum and Nomisma.org alongside the Finnish material ensures that the data service model developed for CoinSampo can be applied across national boundaries.

5 DATA SERVICE AND SEMANTIC PORTAL

CoinSampo will be a single page web application based on the Sampo-UI[32] framework [26]. The application operates by combining faceted search with various data-analytic visualizations. It will offer tools for searching, browsing and data analysis. Compared to some other existing web applications for archaeological data, whether numismatic sites such as the Seleucid coin portal[33] of the ANS or the various European finds recording scheme portals listed above, our portal is more focused on providing tools for analysing groups of entities (such as coins) in the data instead of just finding data about a certain entity. The user can access the data by using a two-step cycle where the target group (in our case numismatic finds) is first filtered out using faceted semantic search [49] and then analysed quickly using the visualization tools provided. In faceted search the final target group is defined step-by-step, using facets that represent different aspects of the searched entities, such as material or object type, with all the available options shown and hit counts on the facets recalculated after every step. This empowers a search and exploration approach where the user does not necessarily have to immediately know what groups of entities would be interesting, but uses an iterative process to discover such groups in the data.

This means that while a user can use the faceted search to find information on, for example, one specific coin of interest, they can also use it to narrow down a group of entities based on some criteria and then visualize the results in various ways. A specific issuing ruler could be easily selected from the ruler facet, and the results then viewed on a map[34] that shows the spread of find spots for those coins, as a statistical breakdowns of the pertinent denominations and mints, by the chronological distribution of coin finds, or as a network graphic linking mints and findspots. Any user, without any training in or access to statistical software, can begin to examine the data as an integrated body of material culture evidence from multiple analytical perspectives. The data analysis tools are designed to be easy to use so that they are not only accessible to professional researchers, but also to hobbyists and indeed all members of the public.

As noted, the integrated search-and-analyse functionality rests on the data – the archaeological and numismatic object records – being described using controlled and ontologized vocabularies. In CoinSampo this mainly means mapping the concepts to the Finnish MAO/TAO Ontology as well as to Nomisma.org for international interoperability. Over the last few years, the FHA, in conjunction with the Finnish Terminology Centre, has developed important archaeological ontologies describing object types, historical periods and other key concepts required for harmonizing and linking heritage data [45]. Considerable research remains to be done across the

[32] https://seco.cs.aalto.fi/tools/sampo-ui

[33] https://numismatics.org/sco/

[34] We use various map services and libraries provided by, for example, the FHA, Mapbox, OpenStreetMap, and Leaflet to render different types of maps.

full field of archaeological sciences, from adopting shared concepts for scientific material samples to describing cultural heritage landscapes, but the foundation is being laid down.

In addition to empowering the Sampo search-and-analyse knowledge discovery engine, further knowledge discovery and learning potential is achieved by linking records located within an ontological framework to national and international resources using stable URIs. For instance, a user examining a specific coin denomination could access a list of rulers that have issued the type, and in turn these rulers are linked to their Wikipedia entries. Additionally, the user could access links to other online archives with coins of the same denomination.

The coin base in Finland was historically highly international. In this context, and given a strong existing foundation of shared numismatic typological practices, the Finnish coin data makes an excellent case study in LOD harmonization. The Nomisma.org paradigm will serve as a base for sharing international numismatic data in the future. Creating controlled vocabularies for so many potential classes across the whole history of coin use, however, is a huge undertaking. Because the current Nomisma.org vocabularies largely pertain to the classical era and to limited geographical coverage, only a very small number of the denominations and other concepts necessary for describing the Finnish coin finds are currently available in the existing vocabularies. As this work is still ongoing, we cannot currently create RDF data from the Finnish coin finds that could be fully integrated into Nomisma.org. We can, however, at a minimum, use the elements of the classes and properties of the Nomisma.org ontology. This will make the data more interoperable, and ease full integration in the future. The concepts used can be mapped to Nomisma.org concepts when they become available.

The potential benefits to be gained from using internationally shared vocabularies for all numismatic data are evident. A standardized ontology makes it is possible, at least in theory, to develop a single data service model to disseminate and display data from digital coin archives from all around the world that conform to the agreed-upon paradigm. This is a very powerful concept, and one that turns the traditional standards in institutional cultural heritage data (i.e., unique data models based on deep institutional histories) on its head. It not only enables enriching existing data by connecting it to other relevant publicly accessible resources, but also greatly facilitates merging datasets for computation analysis.

Therefore, while the CoinSampo framework is specifically built to serve Finnish numismatic material (and will be integrated with the FindSampo service), we are working in parallel towards a framework keyed to the Nomisma.org ontology. Once ready, anyone could in theory install the application on their own computer, download one or more of the numismatic datasets linked to on Nomisma.org, have it ingested by the framework, and then use the application to examine and visualize the data. Next, we will discuss in more depth selected case studies for using CoinSampo to open Finnish coin data that illustrate the use potential of our approach among several key user audiences.

6 COINSAMPO USE CASES

The aim of the CoinSampo data service is to make it easy to find information on coins recovered in Finland, with the particular advantage of being able to examine broader patterns in coin use and circulation across large geographical distances and long periods time. As noted, the service is aimed at anyone interested in coin finds and numismatic data, but four main user groups have been identified as: (1) metal-detectorists, (2) numismatic researchers and archaeologists, (3) local historians, and (4) professional collections managers. All groups benefit from the data analytical and visualization tools in CoinSampo, and membership in the groups may overlap, but users in these different categories might also deploy the applications in different ways. To demonstrate the utility of the service four example use cases are presented.

Metal-detectorists. The metal-detectorist who is producing the new find material – whether a more casual hobbyist or an archaeological citizen scientist – is naturally also the person with the most questions regarding their finds. If the finds are either only catalogued in the collections without opening the data or alternatively returned to the finder without creating a permanent record, their significance as historical evidence will remain

unappreciated. Since most coins from the Early Modern and modern periods are returned to finders in Finland, it may even be unclear why these should be reported in the first place despite the legal obligation to do so. In CoinSampo the full record of all reported coin finds is represented, showing how this new body of crowd-sourced archaeological evidence is being built up over time through the activities of the detectorists. Many detectorists consider certain coin types, for example, the late medieval and Early Modern hand-struck Russian wire money (minted between the mid-14th and early 18th centuries), to be particularly interesting. Therefore, some of the most important features are the record catalogue view powered by the faceted search based on controlled vocabularies, together with the point location and kernel density maps. These make it easy to examine the different coin types reported and to investigate their broad landscape or other geographic contexts (see Figure 2).[35]

Unlike in some other European countries that have treasure legislation governing small metal finds, such as England[36] and Denmark,[37] the fees paid for the objects in Finland are based only on their metal and scientific value and not the market value. As Finnish archaeological objects made of precious metals are typically small (e.g., rings, coins) the financial benefit of reporting objects is relatively insignificant; in 2021-22 the mean fee size was only around €100. Instead, the system relies on the good intentions of the finders and on their interest in producing knowledge of our common cultural heritage.

Opening the finds material to the general public encourages a culture of responsible detecting. Doing so in an accessible data-visualization rich manner is a concrete way of proving to the finders the importance of reporting their finds, and showing how this will generate new archaeological and numismatic knowledge. Importantly, being able to view finds data as a whole body of archaeological evidence recontextualizes metal-detecting away from 'treasure hunting' for showy individual objects, such as coins made of precious metals, jewellery or weaponry; this is something that existing European treasure legislation arguably, if inadvertently, contributes to by officially valuing (by their finder's fee structures) certain object or metal types over others. Less charismatic items, such as various domestic tools or common copper coins, may not be as exciting or as valuable finds on their own. But connecting such objects together through mapping and other analyses shows how each individual find contributes to grander narratives about the past, and thereby supports the development of a citizen science paradigm for hobby metal-detecting.

Researchers. Most often coins as material culture evidence are studied by numismatists or archaeologists, but the term researcher might here refer to anyone using the data for purposes of investigating past phenomena through scientific methods, and includes both professional academics and non-professional citizen scientists. CoinSampo can be used as a tool for studying geographical, temporal and statistical patterns among different coin types on different spatial scales, from national through regional distributions to local finds. The data opened in the service also serves as excellent reference material for coins that have been found by archaeological excavations. For instance, an archaeologist might be studying finds from an Early Modern (16th to 18th century) town in Finland. If the area remained settled, coins from the later periods are usually also encountered among the excavated finds. A case example could be the recent excavations in the market square in Turku, formerly the largest town and the administrative capital of pre-independence Finland [50]. The archaeologist might wonder if the numbers of Early Modern coins found is exceptional, or if the number of coins from different periods reflects the history of the town, or even individual events in its past. Using the CoinSampo statistical tools and faceted search it is easy to check how common a given coin type generally is. The kernel density 'heat map' and the pie/bar chart functions, for example, immediately show that Swedish copper öres from the 18th century are very common finds, found everywhere that coins are reported. Silver öres from the same period, on the other hand,

[35]The map shown here is a screenshot from the CoinSampo application. To generate the map visualization, the application in this case uses Mapbox service (https://www.mapbox.com/about/maps/) which uses map data from OpenSreetMap (http://www.openstreetmap.org/copyright).
[36]https://www.legislation.gov.uk/ukpga/1996/24/contents
[37]https://natmus.dk/salg-og-ydelser/museumsfaglige-ydelser/danefae

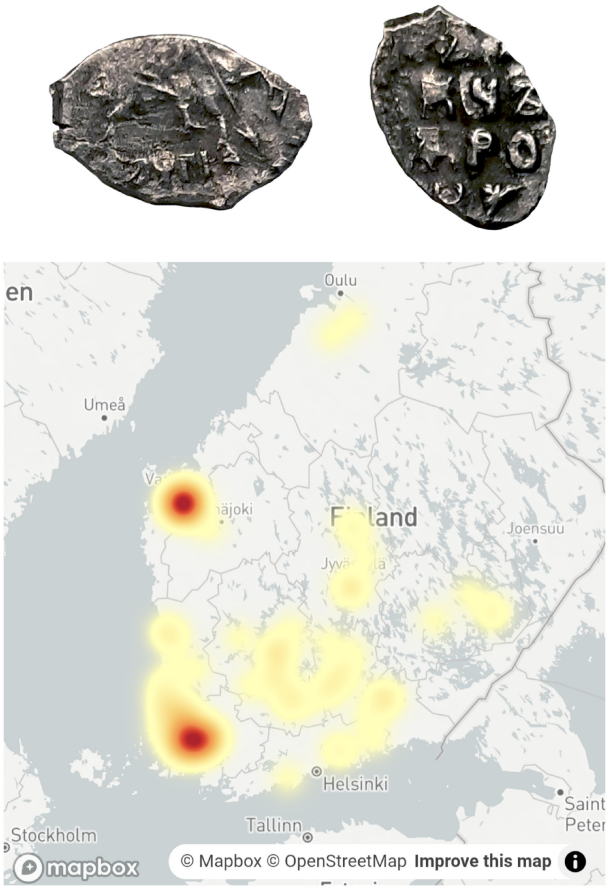

Fig. 2. Geographical and historical processes: a kernel density estimation 'heat map' showing the find locations of wire kopeks issued by Peter the Great, and a Russian wire coin minted in 1713. During the Great Wrath (1714–1721) the area of present-day Finland was occupied by Russia. Russian wire coins from this period are therefore also common finds in the western part of the country. Ilppari report no 14577/find record no 306935. Photo: Finnish Heritage Agency. Basemap: © Mapbox, © OpenStreetMap.

are quite rare. In the same manner, coins from different periods or with various geographical origins can be studied in order to reveal changes in coin circulation patterns across time. If values such as weight or diameter are recorded in the data, these distributions among selected coin types or periods can also be easily compared with a line chart tool.

Local historians. In this example use case a local historian, or any person simply interested in their local cultural heritage, can use CoinSampo to investigate coin finds made in their municipality. Here we chose Savonlinna, a town in the south-eastern part of Finland, founded in 1639 by the medieval Olavinlinna castle. For much of its history Savonlinna was a border town between the kingdom of Sweden and the Russian Empire, and following the Russian conquest of Finland in 1808–9 remained a major regional centre in eastern Finland. Altogether 334 coins have been reported from the area since 2014. Zooming into the map[38] it is easy to see where the finds

[38]The map in this figure is based on the Senate atlas, provided by the Semantic Computing Research Group. Leaflet library (https://leafletjs.com/) is used to draw the markings on the map.

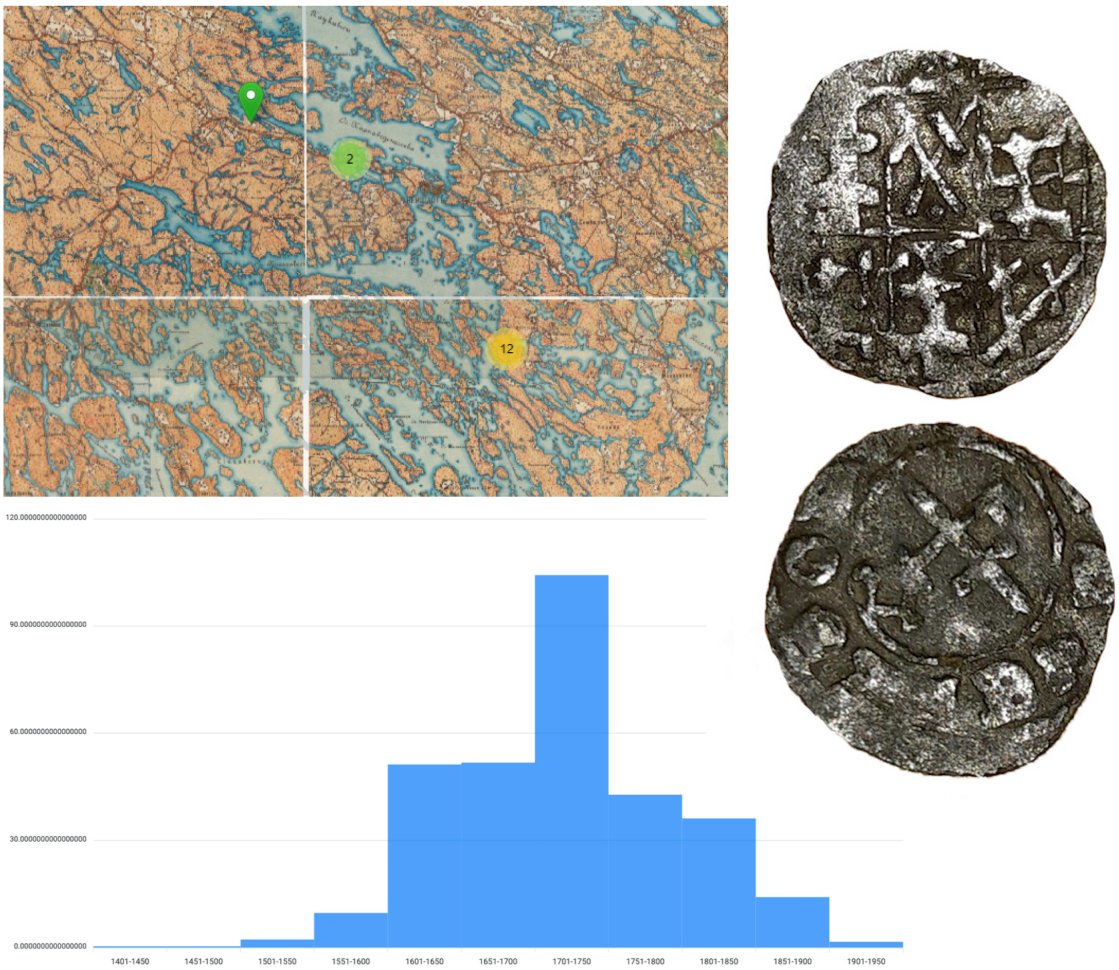

Fig. 3. Local contexts: a map showing the find spots of the oldest coins from the Savonlinna area, placed on the Senate Atlas. The Swedish örtug and the Estonian penny referred to in the text were recovered at the site indicated by the number 2, immediately due west of the town. To the right, a penny minted in Tartu under Johannes V Blankenfeld (1518–1527) and below an aoristic bar chart showing the chronological distribution of all coin finds. Map: mapwarper.onki.fi, Kansallisarkisto. Coin: Ilppari report no 17236/find record no 310556, photo: Finnish Heritage Agency.

have been made (see Figure 3). Using the aoristic tool the user can investigate the chronological distribution of the finds, noting that the significant increase of coin finds in the first half of the eighteenth century matches up with the overall increase of coins in circulation in Finland during this period. An examination of the origin (by minting place and issuing ruler) of the coins with the bar/pie chart statistical tool reveals a fairly even distribution between Swedish and Russian coins, as befits a border region.

The faceted search makes it easy to locate the oldest coins from the area: a Swedish örtug from the late medieval period and a penny minted in Tartu, Estonia, between 1518 and 1528. On the map one can see exactly where these coins were found: only a few kilometres from the modern centre of the town. The map view incorporates georeferenced historical maps, such as the Senate Atlas, an early high accuracy map of Finland (scale

1:21,000, compiled between 1870 and 1907).[39] From it we see that the coins had been recovered by a nineteenth-century road that led west towards the settlements of south-central Finland, which suggests the road's even more ancient character; supplementary cultural landscape data is available through archaeological monument locations ingested from the FHA *Muinaisjäännösrekisteri* database. The essential numismatic information has been recorded and can be historically contextualized through the CoinSampo service.

Collections managers. From a collections manager's point of view, the faceted search function of CoinSampo is ideal for error detection. First, it is easy to see problem points related to the use of controlled vocabularies and ontologies. If recording work has not been done systematically, there might be several alternative entries describing the same coin type, historical period or other key concepts. These discrepancies must be corrected in the canonical database. Second, in CoinSampo one can sieve the numismatic material by period, ruler or mint origin, making it easy to detect erroneous records. A coin by a Viking Age ruler, for example, cannot also be dated to the 16th century. This might sound like a minor matter, but with thousands of objects and entries, many of which have been partly made through copy-pasting information from older records as a time-saving strategy, errors occur and are easily duplicated. Being able to detect these errors and to correct them is a remarkable improvement to data quality and the process of cataloguing objects. This error detection can be done by the collection manager or by adding a simple report error function, available to any user of the service. Finally, by presenting large materials as an integrated whole, curators are able to critically examine and assess the composition of the entire collection. Lacunae, as well as particular strengths, in the body of the material are rendered more identifiable. This may assist future decisions about acquisitions policies or with regard to research on planned exhibitions.

7 DISCUSSION

Through Open Data semantic platforms, such as CoinSampo and other Sampo services, anyone can participate in cultural heritage data analysis. It is a stated aim in Finnish collections management policy planning to meaningfully open collections to the public, and the development of accessible data services is important for putting this material into everyone's hands [45].[40] To meet this need, and especially given the emergence of archaeological metal-detecting and citizen science in Finland and elsewhere in Europe, we argue that there is an urgent need to continue developing semantic and data-visualization rich services to truly achieve **FAIR** data principles[41] (**Findable, Accessible, Interoperable and Re-usable** data) in the international dissemination of archaeological cultural heritage. Most numismatic (or other archaeological cultural heritage) online data services incorporate only sparse data visualizations, typically a basic mapping tool. A few portals, such as the newly released ARIADNEplus portal[42] or Artefacts.mom.fr[43] for European and other international archaeological data, already go a step further and also incorporate a few other data views such as chronological breakdowns.

Taking this yet further, what differentiates the CoinSampo design philosophy from most other online numismatic databases is that it seeks to seamlessly integrate an intuitive faceted search tool with a larger selection of data analytics. These fast and easy tools become part of an integrated search-and-analysis feedback process for analysing, modelling and visualizing data in the portal. In Digital Humanities and semantic computing, the related concepts for these are Data Exploration and Knowledge Discovery, and even Serendipity as one may come across interesting and relevant structures in the data that one did not even expect to encounter [16, 23]. Even experienced researchers involved in archaeological data sciences-driven work will benefit from the tools provided – for example, by using them to pre-filter complex and messy datasets or to produce quick analyses

[39] http://mapwarper.onki.fi/layers/5
[40] https://www.museovirasto.fi/uploads/Arkisto-ja-kokoelmapalvelut/Julkaisut/kokoelmapolitiikka-2015-02-03.pdf
[41] https://www.fairdata.fi/en/about-fairdata/fair-principles
[42] https://portal.ariadne-infrastructure.eu
[43] https://artefacts.mom.fr/en/home.php

Fig. 4. Between two worlds: a pierced coin imitation, found at Nousiainen, Varsinais-Suomi, Finland, in 2020. The obverse of the coin imitates a Byzantine miliaresion and the reverse an Islamic dirham. A similar imitation has been found in Estonia across the Gulf of Finland, in a hoard with a terminus post quem of 1089, suggesting a regional origin. National Museum of Finland, KM 44619:1. Photo: Frida Ehrnsten/Finnish Heritage Agency.

that point the way for more nuanced work in R, Python or dedicated statistical programmes as a considerable time-saving device.

We therefore emphasize the potential of new semantic technologies to enable research along several new axes. Combined with the data harmonization initiatives of Nomisma.org, the CoinSampo approach has the potential to facilitate new scientific research on coin production and circulation on a large historical scale, and among societies and regions that had very different levels of economic development (e.g., monetized or bullion economies). This plays into larger research developments in the Humanities, as Geographic Information Systems-led and other computational approaches have demonstrated new possibilities in deploying archaeological citizen science generated big data to better understand economic change at different geographic scales and across long periods (e.g., [36, 37]).

We point to Viking Age coins as a case of special interest that illustrates this point. The fact that coins were (in Finland, as in many other parts of northern Europe) used as bullion and valued by their weight (in silver) rather than their denomination, made Viking Age coin circulation international, creating socio-economic links between countries in Europe and beyond. This is well encapsulated in the Finnish material, where the two main groups of coins used were Islamic dirhams and European pennies [47]. The region was located by major intercontinental travel routes that extended from the Atlantic seaboard via the Baltic Sea to the great river routes of eastern Europe and into western Asia. This underlines the necessity of bringing numismatic data together from transnational sources to better appreciate world-historical large-scale patterns in economic growth, travel and monetization (see Figure 4). These perspectives for assembling, investigating, understanding, harmonizing and disseminating numismatic data on a large scale can naturally be extended to all metal-detected archaeological data, as has indeed been demonstrated by recent scholarship on metal-work material culture diffusion internationally across Europe [9].

The international use potential of LOD numismatic services extends to professional and non-professional users outside our current core target demographics. A good example is customs agents and police officers working in heritage protection. It is recognized that illegal trade in archaeological artefacts is an international problem, and that within Europe illegal metal-detecting contributes to it [8, 18]. It is difficult to monitor and trace this traffic, especially when objects (frequently coins) are sold across borders on websites such as eBay.com. Digital solutions to support schemes in tackling the problem, such as the partnership between eBay and the PAS,[44]

[44] https://finds.org.uk/treasure/advice/schemeandebay

are being developed but new initiatives continue to be required. The model for heritage data service developed in CoinSampo could be used in the future to identify and provenance illicit artefacts by creating a vast, freely accessible and easily operable analysis-driven reference catalogue including object imagery for professionals involved in heritage crime law enforcement, and thereby helping to protect material culture from black market operators.

We furthermore aim for the CoinSampo data service to be also useful for heritage professionals in museums who will then gain a better understanding of the particularities of their collections. LOD and semantic research will facilitate collections management in providing linked, up-to-date data on the coins, the typological definitions of which are seldom absolute and might change through new finds. In Finland, but certainly also in other European countries, definitions of coin typologies found in old museum catalogues are often outdated and may derive from publications made in the 19th century. The exploitation of already frequently underused legacy archaeological collections and dataset resources has been further hindered by the requirement to master complex specialist statistical software. Compounding these problems are the very limited resources allocated to collections management and the small number of museum professionals working on collections, who seldom have the resources to examine all the available material extensively. An entire collection may rely on individual expertise – in Finland only one person is currently dealing with the numismatic material for both the National Museum and the Heritage Agency – which may not be a sustainable state of affairs on a longer term.

Semantically intelligent data services lessen the curatorial load and empower others to share in collections management. Though its potential is not yet realized in Finland and will form future work that the *DigiNUMA* and *SuALT* projects have pointed the way towards, citizen science-led information provided by amateurs (especially avocational detectorists, who often possess considerable scientific expertise on archaeological and numismatic typologies) can also be of great help in processing and updating records [52]. As volunteer recording programs, such as PASt Explorers in the UK, have shown [32], it is possible to use an inclusive citizen science approach and public participation for much more than just collecting stray finds. The significant hurdle is in creating the data in the first place: in cataloguing, researching, providing information on findspots and in enriching the information by contextualizing the finds in their historical and archaeological landscapes. When open cultural heritage data services incorporate a straightforward feedback function, where interested users can not only examine but identify and provide further information on objects, this can lighten a heavy administrative burden.

8 CONCLUSION

In discussions of new digital cultural heritage solutions, it is professional research and management needs that are typically placed at the forefront. This is unsurprising and understandable, given the communities and stakeholders involved. But for numismatic cultural heritage – as is the case for many other premodern object categories as well – the overwhelming majority of new data and finds that enter the collections are produced by members of the public, especially metal-detectorists. This mass of new data sets new targets for national and international public heritage platforms to meaningfully open their data for learning and study. Advanced data visualizations and embedding record data within existing LOD frameworks will show the public the connectedness of national bodies of heritage material, situate them within local contexts enriched with historical information, and contextualize them within wider world-historical patterns.

Finnish heritage institutions are committed to enabling learning and new knowledge discovery for a wider body of interested participants. Cultural heritage belongs to all, both to citizens and the researchers, not to the keeper of the collection who controls access to it. From a traditional collections management perspective this is a substantive paradigm shift. To be fully effective, however, this model requires developing new heritage management workflows and approaches, as well as the technologies that allow those interested to responsibly engage with the material beyond simply reporting it. On the wider social level of this ongoing conversation, access

to cultural heritage is enshrined in the Faro Convention[45] as a human right. By building a publicly accessible digital infrastructure that embraces and links together historical material culture not just as a closed national phenomenon but as transnational heritage, these participatory and international approaches counter narratives empowering exclusion and discrimination.

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