Introduction

Over the past decade, significant investments have been made worldwide to promote mass digitisations, and to build data platforms to support large-scale research and innovation in the cultural heritage sector. While undoubtedly useful, these platforms were not originally designed to facilitate deep interaction with digital materials or to encourage new research approaches. The COVID-19 pandemic highlighted the limitations of these platforms as digital collections became the only available sources for research, underlining the urgent need to explore strategies to define digital collections as primary research tools and to fully support scholars working in the digital space.

To date, no attempt has been made to systematically and rigorously investigate the potential and limitations of digital collections as a primary research support asset, or the impact of these platforms on how digital collections are constructed and how knowledge generation is facilitated through this construction. When we examine how information is organised in physical archives, we find that space and records are part of the same design. These environments are built to allow users to retrieve, read, compare and, most importantly, enjoy the records. How can we bring these elements into the virtual space, and what characteristics should a virtual environment have in order to trigger such a dynamic interaction?

The Dynamic Collections project was created in a collaboration between the Visual Computing Lab ISTI-CNR in Italy and the Lund University Digital Archaeology Laboratory DARKLab, Sweden, and officially launched the online platform in December 2020 (*Ekengren et al, 2021*). The initial aim of the project was to create a 3D archive to showcase the archaeological reference collection used in the courses in artefact analysis at the Department of Archaeology and Ancient History, Lund University. Once the digital artefacts were available, they were used by different teachers who, after testing the dynamic collections, began to suggest new artefacts to be included and new functionalities to be added. As a result of this socio-technological development, Dynamic Collections was implemented with new interactive tools and with further artefacts from the Historical Museum of Lund University, and later with artefacts from the Blekinge Museum and the Historical Museum in Stockholm. The number of digital artefacts continues to grow, and currently includes 430 high-resolution archaeological artefacts from the Stone Age to the Middle Ages in Scandinavia. The web system has been implemented to facilitate data re-use and to support multiple interpretations and narratives. Currently the Dynamic Collections are part of the Swedish National Infrastructure for Digital Archaeology and are the largest 3D data repository for archaeological artefacts in Sweden.

Related work

Tools and techniques for recording artefacts have increased significantly in recent years. Awareness of the potential loss of cultural heritage and limited access to tangible historical objects has driven this growth. As a result, an increasing number of curators are turning to 3D technologies for tasks such as documenting, preserving, analysing and sharing artefacts (*Arnold & Kaminski, 2014*; *Wachowiak & Karas, 2009*).

However, despite the various advances in 3D visualisation, determining the precise role and potential of 3D archives in generating new knowledge remains a challenge. This leads us to question whether these 3D archives will significantly impact higher education and research, and in what ways they can have an impact on current practice. One possible strategy for addressing these questions is to begin to develop strategies and tools aimed at transforming 3D archives into valuable assets capable of effectively facilitating dynamic and multimodal engagement with and between users (*Drennan, 2009*; *Hurcombe, 2007*; *Di Giuseppantonio Di Franco et al. 2018*).

Three-dimensional models offer the ability to perform tasks that cannot be replicated with physical objects. This data opens up opportunities for users to explore new ways of interacting with the represented material (*Campanaro et al. 2015*), helping to reveal details that often go unnoticed using more traditional methods. However, for these data to be useful in education and research, they need to meet certain quality standards and should be shared on platforms that allow for easy interaction and reuse (*Scopigno et al., 2017*).

For 3D artefacts to be truly effective, they need to comply with the FAIR principles (Findable, Accessible, Interoperable, Reusable) (*Wilkinson et al., 2016*) and to be made available on digital platforms that support advanced learning and the formulation of new questions.

The Dynamic Collections

The core idea of the project was to build a digital equivalent to the reference collections typically used in academic institutions and museums. What we wanted was an archive of digital objects that could give the user the possibility to interact with 3D models in a meaningful, effective way, but also make it possible to create/interact with/collaborate on customised, dynamic sets of those objects.

Ideally, a digital collection must be something more than just a list of 3D models with some attached metadata. It should be able to include all those elements that might be used by scholars and teachers to effectively employ those objects in their everyday work in a cohesive and structured way; elements such as notes, reasoning elements, object-specific annotations, cross-links between entities, schemes, etc.

The online system (*Lund U. & ISTI-CNR, 2023*) presents, through a standard web interface, the objects of the archive (Figure 1). Objects are displayed as cards, with a thumbnail and some basic info. A more comprehensive view of all the attached meta- and para-data can be easily accessed by clicking on the card. A simple filtering /search functionality helps the user in navigating the archive. Each object in the archive can be viewed in detail using a 3D viewer in a dedicated page. The viewer page contains multiple rendering options, navigation helpers, and measuring tools. This page also offers a way to annotate the object, by adding text notes, saving views and rendering parameters (including the currently active measurements) as visual bookmarks with associated text, and placing customisable *hotspots* localised on the surface with associated text. These annotations of single objects can then be exported as a JSON file, to be shared and/or saved for future use.

The 3D viewer is based on the 3DHOP tool (*Potenziani & Callieri, 2015*), an open-source framework for the creation of web-based visualisation of complex 3D models (https://3dhop.net/). 3DHOP can be easily configured and customised to implement specific interaction schemes and interfaces. The project exploited this possibility to design an interface that promotes a multi-faceted and versatile use of the 3D object, by providing simple but flexible navigation, coupled with multiple rendering options, and diverse methods to measure the geometry. The annotation interface lets the user add a layer of information geo-referenced on the object geometry (Figure 2).

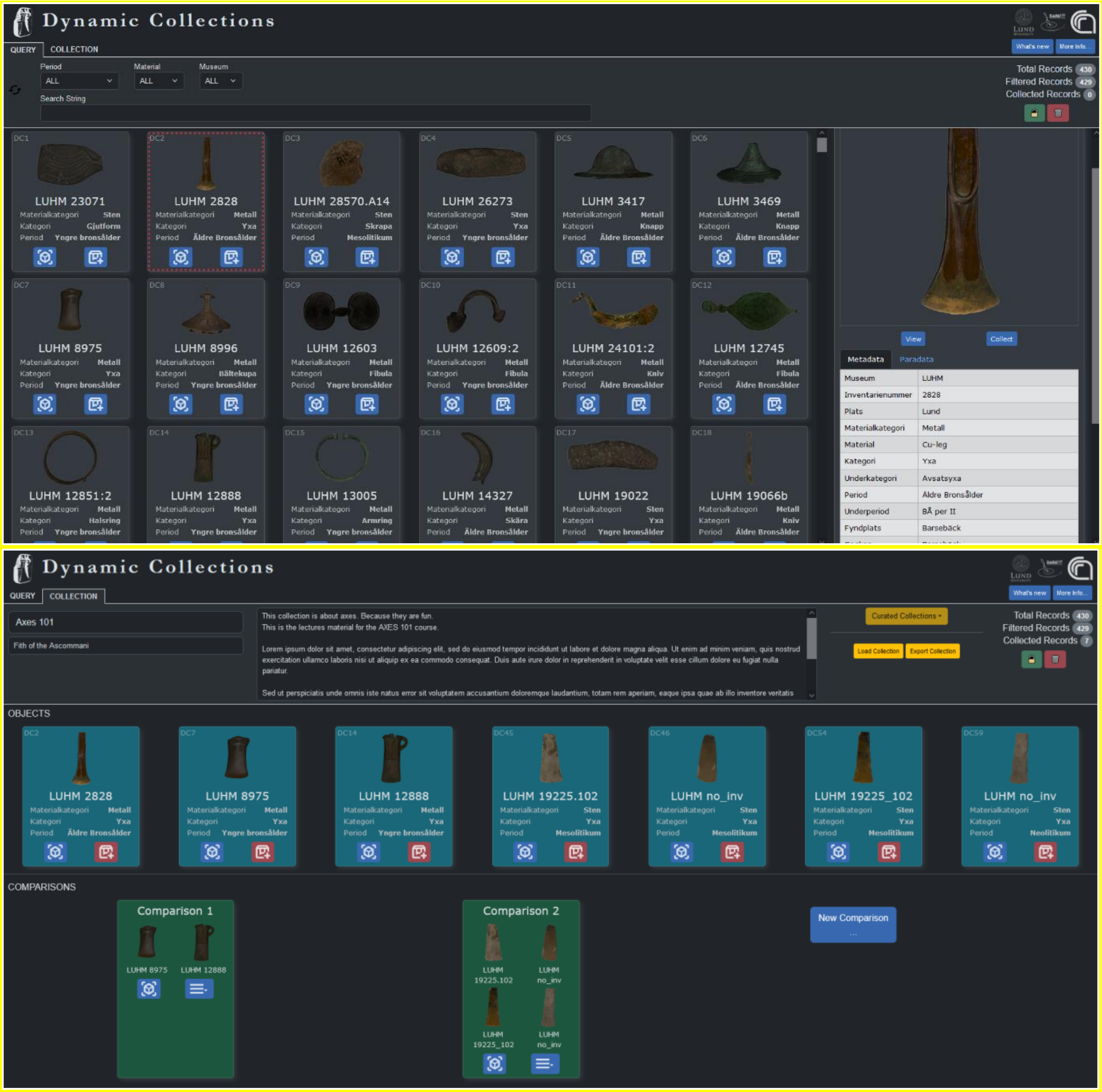

Figure 1 - The online platform, showing all the objects in the archive, with details and metadata (top) and an annotated collection (bottom)

Thanks to the multiresolution scheme used in 3DHOP (NEXUS), the high-resolution digital data is stored in a compressed format on the server and streamed in an effective way to the client. The multi-resolution scheme also helps the real-time visualisation, as the rendering is optimised according to the point-of-view, framerate, memory, and network limits.

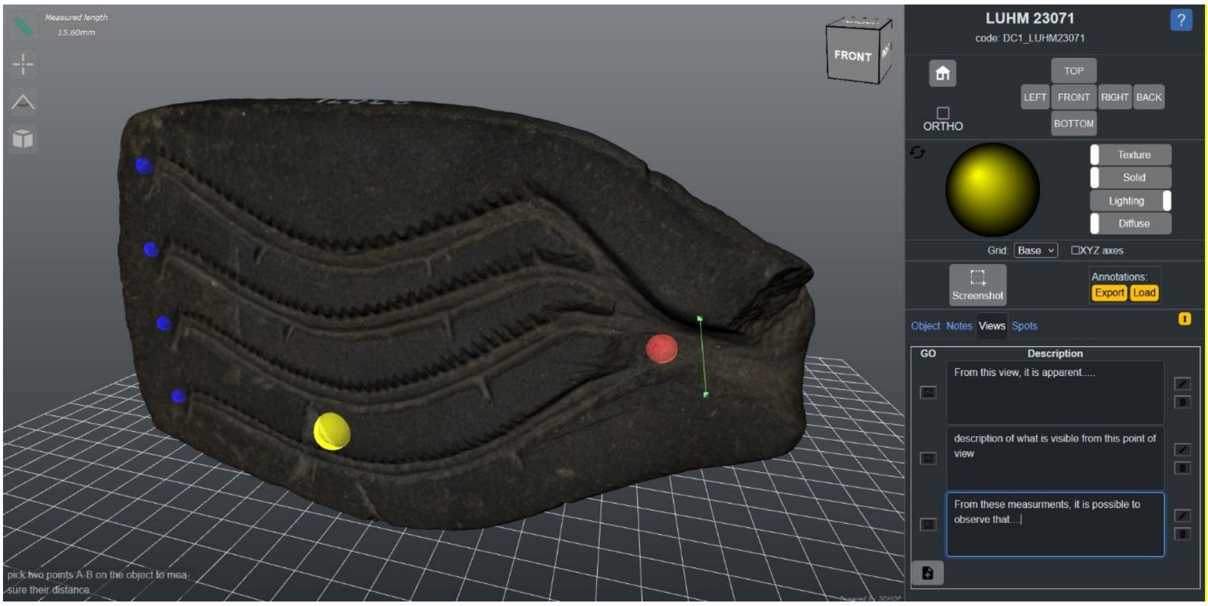

Figure 2 - The single-object viewer, showing an annotated high-resolution 3D model.

The most interesting functionalities, however, are related to the concept of custom-built collections. The user can select objects from the archive, dynamically building a personalised collection that suits their needs. Text notes and other metadata info can then be added to this custom collection. Furthermore, each of the objects in the collection can be annotated using the tools described above; the annotations become part of the collection, thus creating a fully annotated collection.

This annotated collection can be exported as a JSON data structure for future use and sharing.

Upon this concept of annotated collections, it is possible to build complex interactions and workflows between colleagues and students, to pursue a collaborative working/teaching environment.

An annotated collection may be used to represent the working notes, shared between the authors of an oncoming paper. They might contain the candidates for the identification and classification of a newly excavated specimen. Assembled by a teacher, they may be used as a course material, distributed to students, or used as slides during lessons. Compiled by the students, they may be used to take lecture notes directly on the 3D models. Students and teachers may also send the collections back and forth in dialogue, since annotations (analyses, interpretations, feedback etc.) can be added over existing ones. A collection may also be used for specific assignments or tasks to be sent back to the teacher.

An interesting detail of this setup is the clear separation between user data and system data. Everything that is user-created (the selection of objects and their annotations) is contained in the collection data structure, which references the entities in the archive through IDs; conversely, all the 3D data and the relative meta- and para-data are stored only in the online system. Moreover, the creation of the annotated collection is entirely client-side, nothing is ever stored on the remote server: user data is always under the control of its creator. This detail, initially due to a limitation of the platform, became a “selling” point of the tool, as its target audience values this kind of privacy and freedom of use.

Managing and sustaining the project

The core concepts of the projects have been developed in a purely scientific collaboration between Lund University and ISTI-CNR. A number of experiments were done to try working online, for teaching and study purposes, with digital replicas of artefacts. From these experiments, it became clear that, in order to obtain meaningful results, it was necessary to reach a critical mass of 3D objects to interact with and, at the same time, provide multiple ways to interact with these 3D entities.

The generous support from the Thora Ohlsson Foundation made it (and still makes it) possible to start building the digital archive in a systematic way and support the development and curation of the online tools. This initial funding enabled the purchase of 3D scanning and photographic equipment, as well as the recruitment of specialists in 3D capture and data post-processing. At that point, it was clear that the Dynamic Collections was a useful and promising platform, and it was necessary to change how the project was managed, going from an experiment towards a more structured, sustainable initiative, able to survive over a longer period of time.

Further funding was received from the Einar Hansen Foundation in 2020, which enabled the design and development of a new database to expand the Dynamic Collections into a new, more sustainable future. Beside the mere financial stability, in order to grow, it was necessary to establish connections with entities and existing initiatives and projects, since 2022, the Dynamic Collection project is supported by the Swedish National Infrastructure for Digital Archaeology - SweDigArch. The consortium focuses on linking a large number of Swedish archaeological databases (http://swedigarch.se/) to facilitate the production of aggregated and harmonised datasets. Among its many aims, SweDigArch is charged with developing and implementing national strategies for the integration and dissemination of the broad range of digital data and information produced in archaeology.

Due to its ability to generate dynamic interpretations through various interactive tools, the Dynamic Collections platform is currently being used to support ongoing experiments within the activities of TETRARCHs (Telling Stories with Archaeological Data), a project funded by the European Union's Horizon 2020 research and innovation programme, which aims to explore different methods of collecting archaeological data to support different forms of storytelling (https://www.tetrarchs.org/index.php/about/).

Growing together

It is also noteworthy how the development of the Dynamic Collection project influenced, and was in turn influenced by other projects carried out by the involved partners.

An almost exact copy of the online tools of the Dynamic Collections have been used in another Scandinavian initiative: BItFROST, headed by the University of Oslo. Similarly to the main Dynamic Collections installation, the aim was to provide a more structured access to the archive of 3D objects produced by the University Museum of Cultural History. Testing the system on a different archive made all its components more robust, and the different needs emerging from the personnel working in this sister project helped define new possible interactions, analysis, and visualisation options.

The ARIADNE+ infrastructure is an EU-financed (Horizon 2020) project aimed at bringing together archaeological archives and providing services for the common access and use of this data. Among the different services maintained in this framework, the Visual Media Service provides a way to create customisable viewers for high-resolution media. The 3D viewer is based on 3DHOP and integrates some of the interaction components and widgets developed for the Dynamic Collections.

ISTI-CNR was involved in the development of online tools for the digital infrastructure supporting the restoration of Notre-Dame de Paris. Also in this case, some of the components developed for the Dynamic Collections were adapted to the visualisation of a specific class of objects: the stones of the collapsed rib vault. The specificity of this task helped in making the components more generic, robust, and reusable. Some of the specific measurement tools developed for this application were later integrated in the Dynamic Collections viewer.

These connections between projects thus have a positive impact for all the involved parties.

- They help in widening the scope of the projects, as well as defining their needs and approaches, as the presence of different datasets and diverse users provide new problems, requirements, and perspectives.
- They make the development process more sustainable, thanks to the reuse of code and the opportunity to test the tools on multiple, diverse datasets.

- They create an ecosystem of tools, all linked by similar interaction paradigms and data management strategies. This, in turn, influences the community of users, helping the adoption of the involved technologies and approaches.

The presence of a completely open software layer helps this kind of interaction, as it is possible to readily integrate new solutions in the platforms.

Building up the archive

As the project aim was to replicate the concept of a reference collection, we started by digitising artefacts belonging to the local collection of the Historical Museum of Lund University. We started from small-to-medium size objects (5-50cm), as this is the most frequent range in object size, and we based the guidelines of the project archive on this initial selection. We are now expanding towards different classes of objects, especially unmovable ones, like runestones, to also explore and evaluate the benefit of providing this kind of access to objects that are normally not available for manipulation and shared access like the physical reference collections. This will probably require different viewer templates, to cope with the specificity of diverse object classes.

Another direction of development that we are pursuing is the support of multiple 3D models for each object. This development will make it possible to manage and interact with composite objects (this option is already supported in the platform, but it needs a better integration with the rest of the tools), objects with reconstruction parts (mixing measured data with hand-modelled 3D models), and objects with models of different time stages (e.g., before-after a restoration).

To achieve a higher level of shareability of the data in the archive, we are planning to associate to each of the digital entities a DOI. This permanent identifier will make it much easier to use the work done in the Dynamic Collections system in scientific papers and research projects, as it will be possible to “cite” the digital entities. The process will rely on the upcoming possibility of having the Lund University directly assign DOIs.

Data reuse has been a focus of the project since the beginning. The data of the digitised objects has been stored for future (re)use, keeping both the master models in an interoperable format and the raw data. The amount of data stored so far (for the 430 objects) is still manageable at the level of the Lund University, but as the archive grow, the storage policy will have to rely on national infrastructures for data storage, of which the project is already part (SweDigArch). Hopefully, in the future, it would be possible to also rely on international infrastructures like the upcoming EU initiative for a Collaborative cloud for Cultural Heritage (ECCCH). Some of the models of the archive come from pre-existing digitisations, and from different institutions. This ingestion required a small step of metadata normalisation and minimal processing to conform the 3D objects with our conventions. We know that, going forward with the project, the problem of normalisation and data ingestion will become more relevant, and we are preparing for this task through dedicated tools that we are integrating in the new version of the platform.

As a further way to connect the project with university training, MA students have been involved in the acquisition of some of the objects for the archive, as part of their internship within the project. This activity proved to be an interesting and articulate task for the students, as it went beyond the standard “creating any 3D model”. They were given the opportunity to create 3D models suitable for a specific project, following specific rules, conventions, and methodologies, simultaneously providing the project with feedback on the acquisition methods and workflow.

Improving the deep interaction

The core concept of the Dynamic Collections is the deep interaction with the entities in the archive, and how the idea of a dynamically assembled collection may be used for multiple purposes: teaching, study, analysis, discussion, and the sharing of information.

Comparisons

The collection should not be just a set of objects with some attached annotations but should contain other user-created elements representing cross-object relationships and reasoning. A development direction is to design and implement more ways to manipulate and combine the objects in a collection, providing the user with more ways of working with the available entities. The first of these new tools being added to the online platform is the direct comparison of multiple objects inside a collection (Figure 3).

The chosen objects are shown in multiple viewer panels on the same page. The interaction and rendering options are similar to the ones in the single-object page viewer; each viewer panel can be controlled independently, but specific functionalities are available to sync the view and the scale across the panels, for a localised side-to-side comparison. Similarly to the single-object viewer, the user can annotate the comparison, adding notes, and saving specific combinations of views and rendering opinions across the viewers. These comparisons are then stored as new elements of the collection, following the principle of storing in the collection all the user-created data.

The new comparison functionalities are currently their first test version and has been made available to all users in the last update.

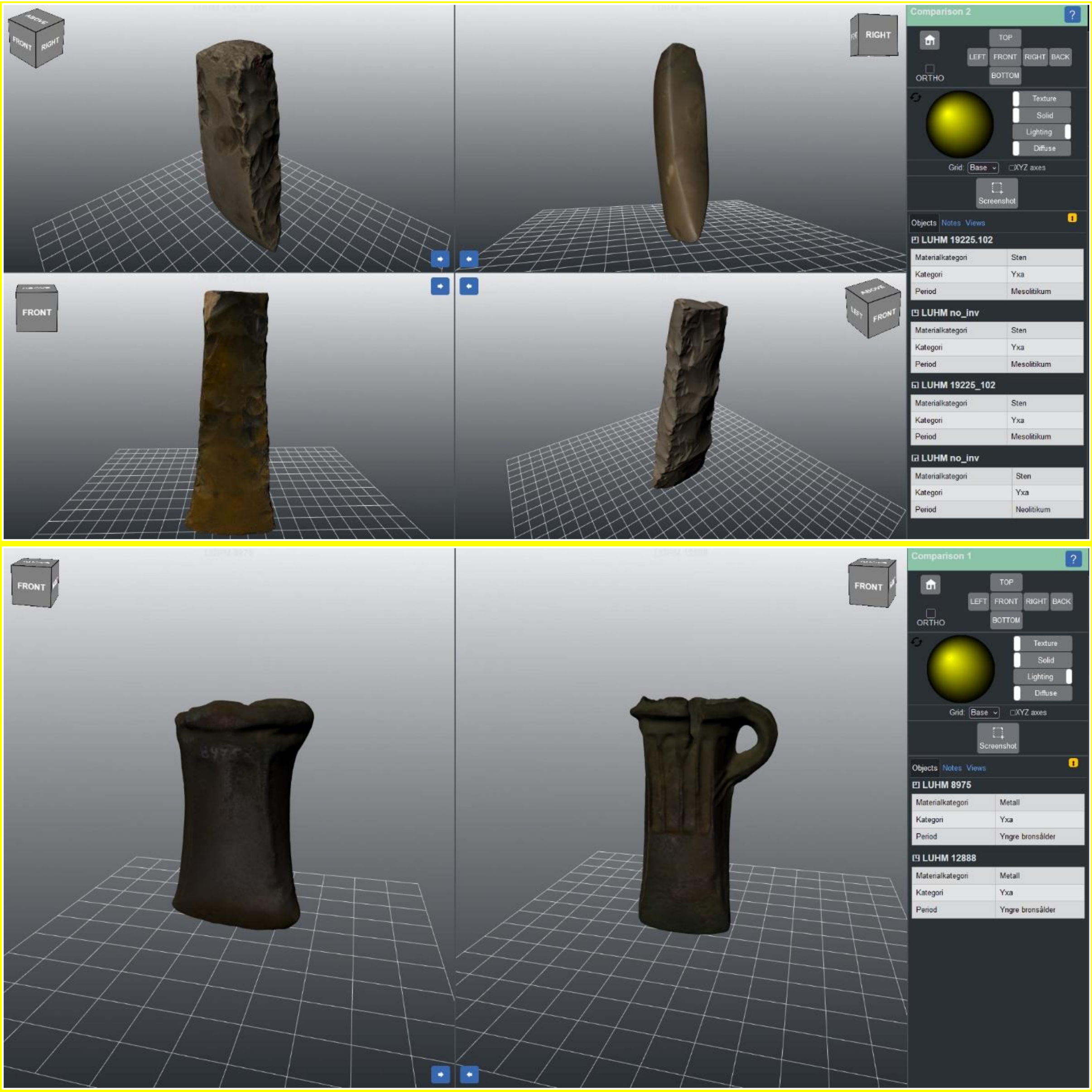

Figure 3 - The new "comparison" entity in the collection can be used to create side-by-side multi-object visualisation and annotation.

Support to teaching

When the system was first designed, one of the main aims was the support of teaching. An annotated collection could be used as teaching material, akin to slides and handouts. The ability to create annotated collections can already be used as a form of assignment, but it could be possible to support other aspects of a course.

The system could be expanded to provide specific tools for the creation and evaluation of tests. The teacher would compile a collection, selecting the object to be included in the test. Then, on a restricted page, assemble a test starting from templates of questions and activities. This authored test would still be an annotated collection, containing new structures representing the individual questions and activities, but still fully interoperable with the rest of the platform.

On another specific page, the students would log and take the test, interacting with 3D models following the teacher-authored questions. The compiled test would also be stored as an annotated collection structure, using other dedicated data structures. To maximise their usefulness, these pages should be compliant with the existing online systems used by universities to manage courses and student activities. This could be achieved by using the university systems as identity providers, and serving the test pages inside the university service, thus managing the annotated collection through a secure connection.

Another interesting problem would be making these components (both the pages and the data structures) resilient to cheating and user manipulation, possibly without compromising the open and interoperable nature of the collection data structure.

Finally, this research direction would also be able to explore the topic of the use of 3D models in an academic test, in terms of interaction, visualisation, and the underlying geometry functions.

This feature is currently being discussed and designed, but the real development has not started yet.

Towards a semantic management of metadata

The main focus of the project has been the interaction with 3D data. For this reason, in the first iteration of the system, we limited to a minimum the amount of meta- and para-data included in the archive. This additional data layer was just meant to help in organising/filtering the objects of the archive and providing the user some background information when inspecting a specific object. However, as the number of objects grows, and the scope of the project widens (in terms of involved partners and available interaction tools) this choice is falling short.

To make the metadata more informative and usable, to help the process of metadata normalisation and ingestion, and to support an easier inter-connection between our project and other existing repositories and archives, we are moving to a fully semantically-mapped management (O'Neill & Stapleton, 2022, Doerr & Ore, 2007) of the metadata of the entities in the archive (Figure 4). The use of semantic-based metadata is also becoming mandatory in many countries for digital archives of cultural data, and it is in line with the upcoming EU efforts related to the European Collaborative Cloud for Cultural Heritage (*ECCCH*).

To be compliant with the existing standards of semantic management of data, the new version of the online system will be based on OMEKA-S, a semantic web CMS (https://omeka.org/s/). This open-source platform supports modern linked data access paradigms, with an API and support to existing ontologies and vocabularies. OMEKA is an open tool, has a lively development community, and it is becoming more and more widespread across research bodies and public institutions.

This choice also responds to another current limitation of the system: not having a structured back-end server. By adding this component to the project, we will be able to provide more structured services, data persistence, and more complex interaction between users. Notwithstanding these advantages, we still strongly believe the usefulness and relevance for the community of being able to use the system without the need of a login and to keep all the data on client side, and for this reason we will strive to preserve this alternative workflow.

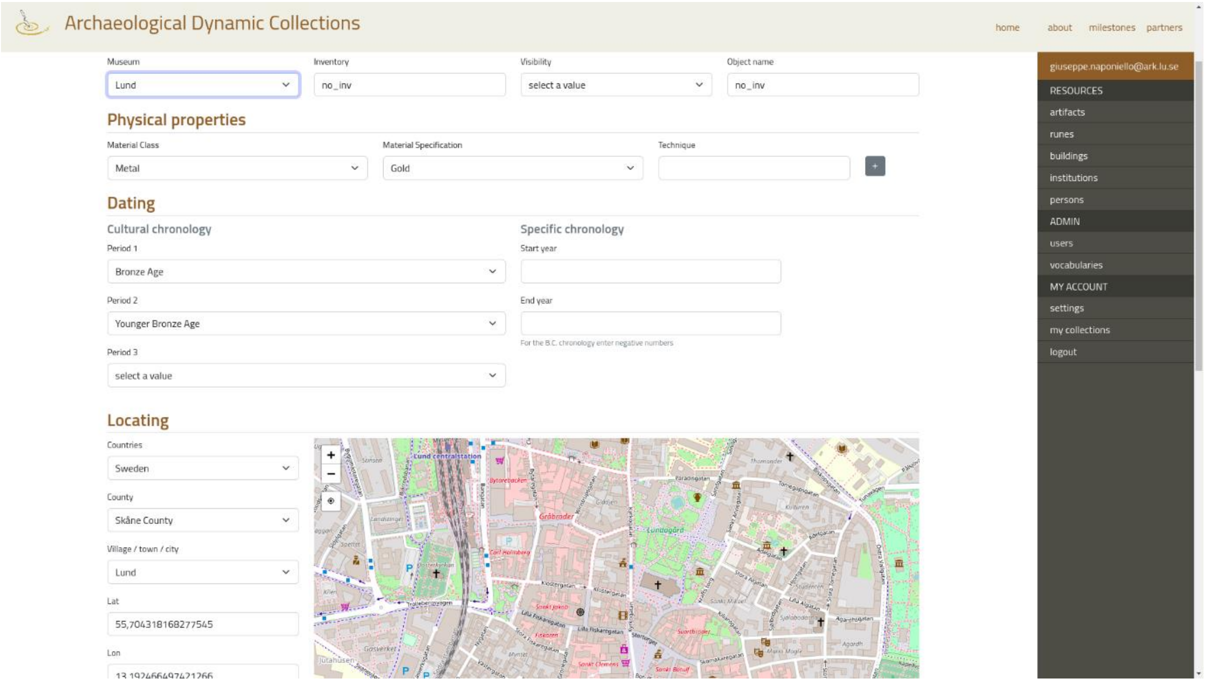

Figure 4 - To support the new semantic-mapped metadata, the authoring tool make use of existing, established ontologies and vocabularies.

The use of consolidated ontologies and vocabularies will surely make this project more interoperable with existing online archives and research projects, but a promising direction would also be the definition of specific ontologies and semantic mapping for entities that are not currently available, such as the concepts related to the 3D aspects of the dataset. A comprehensive semantic mapping would make much easier the interoperable use of things like the 3D scene components, their arrangement and meaning, the interaction and navigation, and all the different ways to annotate the models that are already part of the platform (and the ones in development).

Conclusions

The Dynamic Collection is still an ongoing project, but it has already proved the potentialities of a deep, structured interaction with a digital collection. This has been achieved not just by defining an abstract interaction paradigm, but by implementing and making it accessible as an online platform, to foster experimentation and practical usage. The most interesting contribution of the project is the concept of the annotated customised collection, and the different ways this data structure can be exploited to build complex and practical workflows in the framework of teaching and study activities in the archaeological field. The ongoing work of design and development is building upon these results, to provide new ways to interact and work with the digital replicas of the artefacts, but also to improve the platform to offer a more integrated experience.

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Preprint version 1 of this article has been peer-reviewed and recommended by Peer Community In - PCI Archaeology.

Data, scripts, code, and supplementary information availability

Data are available online: Dynamic Collections platform https://models.darklab.lu.se/dynmcoll/Dynamic_Collections/ (Lund U. & ISTI-CNR, 2023);

Supplementary information is available online: project webpage https://www.darklab.lu.se/digital-collections/dynamic-collections/ (Lund U. & ISTI-CNR, 2023);

Conflict of interest disclosure

The authors declare that they comply with the PCI rule of having no financial conflicts of interest in relation to the content of the article.

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