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From Paper to Web: Automatic Generation of a Web-Accessible 3D Repository of Pottery Types

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Abstract

3D web repositories are a hot topic for the research community in general. In the Cultural Heritage (CH) context, 3D repositories pose a difficult challenge due to the complexity and variability of models and to the need of structured and coherent metadata for browsing and searching.
This paper presents one of the efforts of the ArchAIDE project: to create a structured and semantically-rich 3D database of pottery types, usable by archaeologists and other communities. For example, researchers working on shape-based analysis and automatic classification.
The automated workflow described here starts from pages of a printed catalog, extracts the textual and graphical description of a pottery type, and processes those data to produce structured metadata information and a 3D representation. These information are then ingested in the database, where they become accessible by the community using dynamically-created web presentation pages, showing in a common context: 3D, 2D and metadata information.

CCS Concepts

•***Computer Graphics*** → *Shape modelling;* •***Data management systems*** → *Database design and models;* •***Document management and text processing*** → *Document capture;*

1. Introduction

The research community considers 3D models repositories a hot topic since several years. This is due to the increased availability (and need) of 3D models in a number of application contexts, but also to the advancements in shape-based analysis.
Cultural Heritage is, as usual, a challenging field of application due to the variability in term of shapes, materials, and conditions of the objects of interest. Unfortunately, a CH-related repository cannot rely only on shape information, but a set of metadata and semantically-rich information should be attached to each object to be able to derive knowledge that is meaningful not only from the purely geometric point of view. This paper focuses on the work of archaeological pottery specialists. When classifying sherds, archaeologists rely on existing and consolidated printed catalogs, which are often difficult to find.
Hence, one of the aims of the ArchAIDE project is to build a comprehensive database by processing all the available reference information regarding selected subsets of pottery types. Figure 1 shows a simplified representation of how the reference database will be populated. In addition to the mapping from already existing databases and the fully manual insertion of non-cataloged types, the main source of information is represented by existing paper catalogs.
This paper focuses on the automated part of the database ingestion process (i.e. the blue components in Figure 1). Starting from the scanned images of the catalog pages, our workflow tries to extract both the textual description and graphical depiction of each pottery type, and then parses/processes each of these components to retrieve both a structured metadata information and a semantically-rich vectorial 2D and 3D representation of the pottery type. These data can be easily inserted in the reference database, where the 3D model and all the associated data can be presented to the community using dynamically-created web presentation pages.

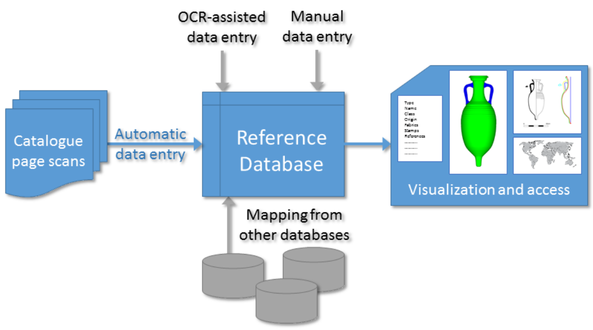

Figure 1: *A simplified scheme of the database creation work flow proposed by the ArchAIDE project.*

2. Related Work

Repositories of 3D models are a valuable source of information for the Computer Graphics community. Content-based 3D retrieval [TV07] is an important challenge that could involve the understanding of the semantic of objects. Several efforts have been done in this direction in the last fifteen years, starting from seminal actions as the *EC "AimAtShape" NoE* [Fal04].
CH is a promising field of application for these approaches, given the massive amount of available items, and the clear potential impact on knowledge and Digital Humanities workflows. However, the analysis of 3D shapes alone may not be easy to integrate with the way CH experts treat items [KFH10]. A set of metadata (or an ontology to connect them) would be necessary to enhance analysis and retrieval. A number of efforts have been studied to create generic ontologies [PSH*13] or to integrate 3D model into already existing repositories [DNBF12]. The peculiar nature of 3D data and the variability of CH items have prevented from the creation of a long-lasting solution.
The more structured nature of pottery has brought to more successful efforts in creating available databases. In some cases, only a part of entries includes 3D models [SKN*14]. The most similar archive to the one presented in this paper was proposed by Koutsodis et al [KCT*08], whose goal was the design of a 3D pottery database to benchmark machine learning systems. Nevertheless, the 3D models in the database were modeled [KPA*09], while our models are automatically generated from the reference drawing in catalogs.
The 3D representation of pottery has been a hot topic right from the beginning of the advent of reliable 3D acquisition technologies. Several projects focusing on archaeological sherds produced 3D representation by means of 3D scanning [KS08, KSM05, CSDR12], but the management of 3D acquisition of sherds outside of laboratory settings is still a difficult task. For example, the proposed automated systems [KS06, Kar10] have not been reached a production quality pipeline to be used by archaeologists.
The ArchAIDE project tools use the sherds profiles without directly working on a 3D representation. In many similar efforts, even when a 3D representation was involved, the classification or analysis was made on extracted profiles [DLS95, KS11, LMCF*14, GKSS04].
Only a few previous works used features extracted from paper catalogs [KS02, MG05]. However, these works did not extract high-level structured features as done with our method.
Finally, the appearance [MD13] and the combination of appearance and shape [PBP13] have been proposed as well. This is one of the future research directions of the ArchAIDE project.

3. Importing the Catalog

Paper catalogs contain most of the reference information that archaeologists need for dealing with pottery. While the structure varies among the different catalogs, a subset of data and a representative drawing are almost always included. Some of the available catalogs are not as structured as expected, and the relevant information is described in a verbose and non uniform way. Hence, a fully automatic database population is hard to reach. However, some catalogs are structured enough to allow us to design a semi-automatic parsing and database population.

The scheme in Figure 2 shows our workflow for the digitization of catalogs. The scans of the catalog pages are first processed to extract the page regions containing drawings and text areas ("OCR Text / Drawing Extraction" in Figure 2). This process may be completely automatic, or assisted, depending on the catalog. Then, automatic procedures are used to parse the extracted texts into structured information ("Text parsing" in Figure 2), and to generate 3D models and vectorial information out of the drawings ("Drawing to 3D+SVG" in Figure 2). The result is a set of entities (a JSON containing the metadata, the "depiction" images, the 3D models, and an annotated SVG) that can be imported in the reference database.
The process and the software solutions, which we developed, are described using, as an example, the first of the structured catalogs we worked on; i.e., the *"Conspectus formarum terrae sigillatae Italico modo confectae"*. The Conspectus is highly structured, with the description of each type following a strict scheme: one class per page, with the same info/lists/descriptive paragraphs in the same order, complying with basic formatting rules, on the odd pages, and with the graphical drawings on the even pages; see Figure 3. We exploited this regularity of its pages to build a tool that automatically parses the scanned page and generating the database entries.

3.1. Processing the Catalogs Scans

The aim of this step is to extract the drawings and the text areas from the scans of the catalog pages. Starting from a page scan, by using simple heuristics and image processing, we can isolate and extract the drawings and the various parts of the text. The tool uses the open-source Tesseract OCR [Smi07] to convert the page image chunks/columns into text, then processed by the parsing module. The drawings are transferred to the 3D generation module.

3.2. Recovering Structured Information from Catalog Texts

This module ("Text parsing" in Figure 2) extracts from the text the information needed to create a new database entry for the specific pottery type. The OCR parses text from the page and, as the Tesseract OCR also returns lots of structural information, such lines and paragraphs, we can isolate the different sections and formatting elements. Following the structure of the pottery type description used in the specific catalog, we extract the metadata.
For example, as shown in Figure 3, all sections in the Conspectus catalog have the same title, the pottery types are a numbered list just after a first, untitled section. When the structured information has been extracted, the tool fills out a JSON structure that can be imported by the database to create a new entry.
Then, the new entries are manually checked and refined by archaeologists because the parsed text may contain errors or ambiguities, or because some manual input is needed; e.g., locations are described with toponyms and they need to be converted into geo-located polylines.

3.3. Extracting Geometric Features and 3D Models from Catalog Drawings

In this step ("Drawing to 3D+SVG" in Figure 2), we process the drawings of the pottery types, extracting the geometric and semantic informations from the catalog image.
Pottery drawings are a technical representation of the different

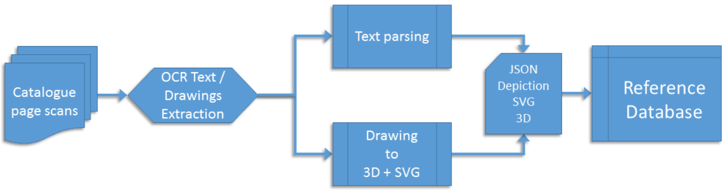

Figure 2: *The catalog processing workflow.*

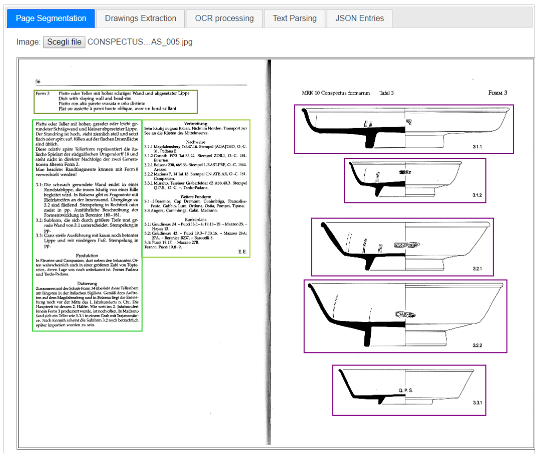

Figure 3: *The scanned catalog page is segmented, extracting the drawings and the text columns/areas.*

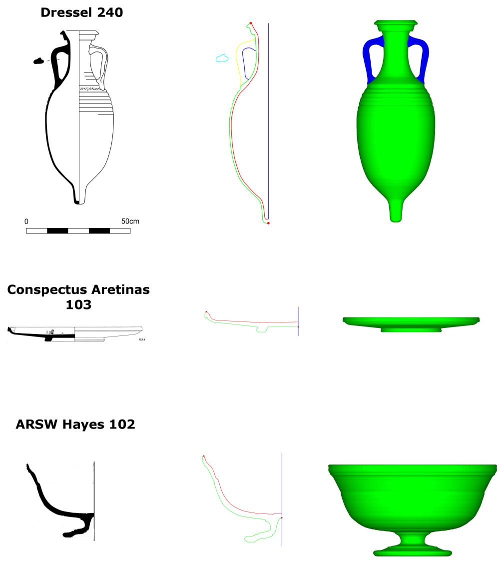

Figure 4: *Some results of the processing of drawing (each one from a different catalog): On the left, the original image. In the middle, the extracted profile. On the right, the 3D model produced from the profile.*

types, which contains a high amount of discriminative information that guides archaeologists in studying and classifying pottery. Nevertheless, all the semantic information is represented with a single raster layer, which follows specific rules (e.g., line and filling style, and axis orientation). We want to generate new representations that can be employed in computer applications: 2D vectorial drawings and 3D models.

This automatic process relies on image processing techniques, exploiting the common representation rules of pottery drawing. A number of geometric features (body/handles profiles, rim, base, rotation axis) are extracted. The profile extracted is then stored into an SVG file, annotated with semantic information. we use the profile to create a 3D model representing the pottery type. As the main body of most pottery is just a rotational object, we can easily create it by sweeping the profile around its axis. The handles are generated separately, extruding their cross-section along their profile, and then welding them to the main body geometry. The result is a watertight, single-surface, triangulated 3D mesh. Additional detail on the drawings processing can be found in [BID*17].
Figure 4 shows some results of this process. We believe that including both a 2D vectorial representation and a 3D model in the database is essential to cover the different needs of different communities. Even though the main target for the database are archaeologists, these semantic-rich geometric representation(s) may also be used by other communities for visual computing purposes.

3.4. New Catalogs and Unstructured Catalogs

Both the text parsing and 3D extraction are not a completely reusable process, as they have been tailored on the text structure and drawing rules of a specific catalog. However, we developed both processes to be configurable and modular, and the parsing/interpreting code can be modified to accommodate for a different catalog.
As stated before, not all catalogs have a structured textual description. This impacts a lot on the text parsing, but it leaves the drawing-to-3D workflow intact. To cope with unstructured catalogs, a different OCR-based tool has been integrated in the database back-end. The user can upload scans of catalog pages and interactively select parts of the scans, the OCR processes these chunks, and the recovered text is used to fill the fields of a new database entry.

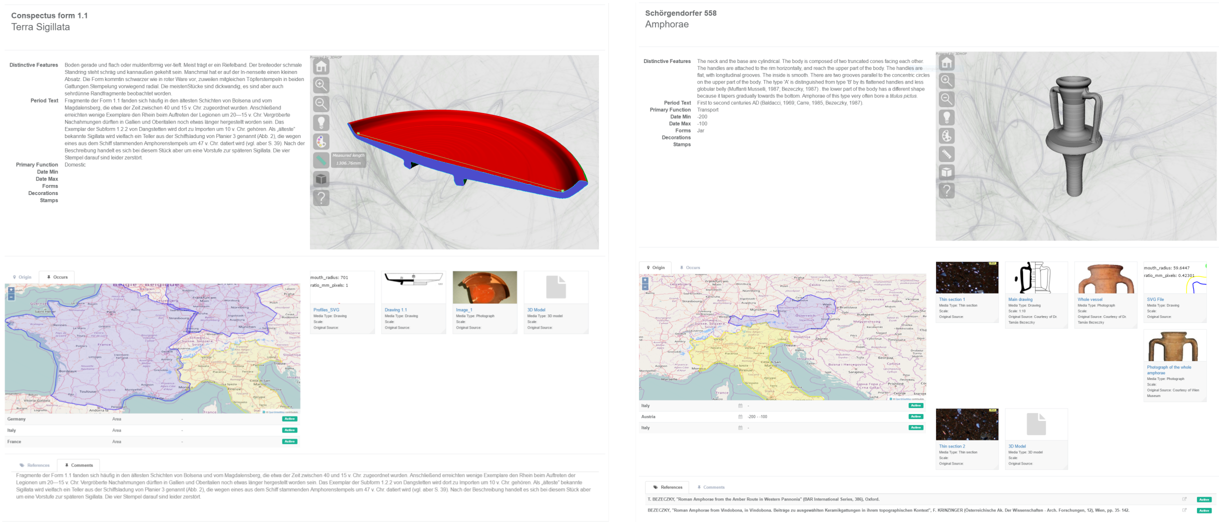

Figure 5: *Two snapshots of a web page generated with input data.*

4. Database Population and Web Visualization

As shown in Figure 1 the database population will be achieved using different methods, beside the pipeline just described. A significant part of the database will be filled from existing archives provided by the project partners. The data will be migrated using JSON XML or directly with SQL queries. Some other catalogs will need a semi-manual or totally manual intervention by users.
Some elements of the described pipeline may be used by the other workflows; e.g., automatic ingestion from existing database may need the generation of the 3D data from the available drawings, following the same approach described in Subsection 3.3.
A major effort during the implementation and population of the database was put on the visualization page associated to each pottery type. In addition to the availability for download of all the associated files, all the important information is directly visible for interactive navigation and visual inspection. Similarly to previous efforts in this direction [GCD*16, PFDS16], the 3D model is preprocessed for a multi resolution visualization [PD16], the default encoding for 3DHOP [PCD*15] (a platform for publishing 3D data on the web), which has been used to provide an interactive navigation of our records.
The coherency of the data (scale, structure, reference space and orientation) allows us to create simple yet informative web pages, which provide all the elements of interest to different communities.

5. Results and Current Features

The population of the ArchAIDE reference database is currently ongoing. The initial goal is to insert three classes of artifacts (with many different types for each class): *amphorae*, *terra sigillata* and *medieval pottery*. In a second phase, we will expand the data population to other classes. The database will be available at the web address `http://archaide-rm.inera.it`.
Figure 5 shows two snapshots of the dynamic web page designed for presenting a type. The pages contain on the top part from left to right: the basic textual fields encoding the description, and the 3D web-viewer of the 3D model. In the middle part, a visualization of origin/occurrences/references, and all the items (photographs, drawings, and thin sections) associated to this pottery type. At the bottom, the references or additional comments associated to the type. Furthermore, the web pages allow users to download the 3D model that was generated from the drawing and the SVG file containing all the extracted geometric features. The 3D rendering of the generated geometry helps in providing an interactive exploration of the object. Although the viewer is basic, it allows users to fully explore the geometry, to measure it, to control lighting, and to activate a cross-section view.

6. Conclusions and Future Actions

We presented an automatic pipeline to process paper catalogs of pottery class types, leading to the generation of a 3D representation for each type, and to the population of a database that will be made available to all the research community.
Regarding future directions of work, the database will contain information regarding three other important and "transversal" features: decorations, fabrics, and stamps. Such features will allow users to classify and compare types.

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