A Cultural Heritage Partonomy for the documentation of 3D digital artefacts of Cypriot coroplastic art

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Abstract. The goal of this paper is defining a Cultural Heritage Artefact Partonomy (CHAP) concerning coroplastic Cypriot art. In particular, two case studies have been considered: the terracotta statues from the port of Salamis, attributed to the Neo-Cypriote style (ca. 600-500 BC), and the small clay statuettes from the Ayia Irini sanctuary, mostly attributed to the Cypro-Archaic period (700-500 BC). Although their differences in size, style and decorations, the items of this study represent male standing bearded figures, sometimes holding animals, arms or music instruments, and provide interesting examples for the description of human figures and their attributes in ancient times. Moreover, 3D digital models have been created digitising the physical artefacts for archaeological purposes.
The objective of this work is framed within the EU GRAVITATE project, which proposes an innovative approach to the study of heritage artefacts, including 3D virtual reconstruction, classification and morphological analysis, steps that are limited by the impossibility to re-unite them physically, either because they are stored in various museums or because physical refitting fails. In this perspective, a controlled vocabulary for the documentation and retrieval of 3D digital fragments and their parts has been developed and proposed here.
CHAP is a SKOS vocabulary, aligned and mapped to CIDOC CRM to integrate the description of the relationships between the parts and the overall context of the two archaeological collections. Focussing on both the artefacts and their digital counterparts, CHAP refers also to the CIDOC-CRMdig extension, where possible missing components have been identified and undertaken.

Keywords: Cypriot coroplastic, Ayia Irini, Salamis, partonomy, 3D models, CIDOC-CRMdig

1 Introduction

Nowadays knowledge technologies guarantee a digital and extensive documentation of many different aspects of complex assets as well as of contextual information in very diverse fields, such as Cultural Heritage (CH). Furthermore, the potential of computer vision and computer graphics methodologies to support the research in CH has recently become more evident: 3D modelling, processing and analysis are now mature enough to allow the management of 3D digitised objects as if they were physical, and then conducting specialised qualitative and quantitative analyses to assist researchers in the field. Bringing geometric and semantic modelling together is the next challenge towards a real digital heritage science.

In the European GRAVITATE project (Phillips et al. 2016), various tools for geometric and semantics-driven analysis of digital artefacts has been realized and integrated to support research in archaeology. The general objective of the project is proposing an innovative approach to the study of heritage artefacts, which includes virtual reconstruction, classification and morphological analysis, steps that are currently limited by the access to physical items and the impossibility to re-unite them physically, either because they are stored in different museums or because physical refitting fails. The context is particularly interesting, as most of the archaeological objects discovered in a survey are usually fragmentary, eroded and broken, documented with traditional archaeological texts describing the content of the fragments verbally and therefore mostly qualitatively.

In this paper we will explore the aspect of the documentation of 3D assets, considering not only as entire artefacts but also the interesting features of the object from the archaeological perspective. Indeed, the goal is supporting the archaeological research and curation providing a different approach to enrich the documentation of digital resources with features and corresponding measurements, combining semantic and geometric tools. This approach does not apply only to the GRAVITATE context, but is able to support archaeological research, where the goal is an extensive digital documentation of tangible findings, including quantitative attributes.

The assets considered in this work belong to the terracotta statues from the port of Salamis, attributed to the Neo-Cypriote style (ca. 600-500 BC), and the small clay statuettes from the Ayia Irini sanctuary, mostly attributed to the Cypro-Archaic period (700-500 BC). Although their differences in size, style and decorations, the items of this study represent male standing bearded figures, sometimes holding animals, arms or music

instruments, and provide interesting examples for the description of human figures and their attributes in ancient times.

In the GRAVITATE frame 3D digital models have been created digitising the physical artefacts for curatorial purposes. In addition to the archaeological catalogue records, they have been documented according to the Cultural Heritage Artefact Partonomy (CHAP). CHAP is composed of three parts: the first classifies the *body parts* and *attires* of the Ayia Irini and Salamis statues; the second the *decorations* and *colour*; the third one the manufacturing *techniques* adopted by the artisans.

CHAP is a SKOS vocabulary, aligned and mapped to CIDOC CRM to integrate the description of the relationships between the parts and the overall context of the archaeological collections. Focussing on both the artefacts and their digital counterparts, CHAP refers also to the CIDOC CRMdig extension[1]. Importantly, since the concepts formalised in CHAP correspond to areas of interest on the artefacts, and such parts can be selected and measured digitally, it is possible to annotate such 3D features with CHAP in a semantic web perspective (Catalano et al. 2011). To accommodate such computational characterisation of shapes, a SKOS taxonomy is not enough and then a suitable mapping to CIDOC CRM and an extension of CRMdig has been defined in this work.

The paper is organised as follows. In Section 2, the archaeological use cases are described. In Section 3, a state of the art on the documentation of digital resources is examined. In Section 4, CHAP is extensively illustrated and Section 5 describes how the semantic model has been exploited in the GRAVITATE platform. Finally, Section 6 concludes the paper, discussing the advantages and limitations of such conceptualisation and outlining future work.

2 Description of the use cases

The research proposes two case-studies from Cyprus to look at part-whole relationships in reconstruction and interpretation of terracotta objects: the terracotta statues from Salamis and the terracotta statuettes from Ayia Irini. The question of provenance of knowledge is about mereology.

The first case study on which the partonomy started to be drafted is the collection of the terracotta statues coming from the port of Salamis. The archaeological site of Salamis is located on the eastern coast of Cyprus. The first excavations of the site are dated back to 1890, when a British Mission excavated the site and interpreted as a shrine (Munro et al. 1891). The site had a long period of occupation, from the XI century BC to the VII century AD, when the Arabs invaded the island and destroyed the site (Karageorghis 1969). The shrine was found on a small rocky hill, called Τούμπα, situated between two rivers, south to the Roman remains. Numerous fragments of statues made of terracotta or limestone were found in the area, as well as ceramics and several other kind of objects. All these materials were interpreted as vows. Particularly, the majority of the statues found at the site represent male bearded figures and they were attributed to the so called Neo-Cypriot style, dated from the second half of the VII century BC to the early VI century BC (600-500 BC) (Karageorghis 1993).

Nowadays, the collection is dispersed throughout several museums and private collections. The vast majority is preserved in the British Museum and the rest is distributed over the Ashmolean Museum, the Fitzwilliam Museum, the Cyprus Museum and private collections. Particularly, the collection of Salamis studied within the GRAVITATE project consists of circa 250 fragments of statues (see Fig. 1). Most of them represent male standing, bearded figures, of different sizes and decorated with painted elements in black, red and rarely also yellow. Some of them hold an animal and some other wear a headgear. The presence of such numerous features, both decorative and structural ones, the specific postures and all their combinations, requires a coherent and hierarchical description, which was missing and would have advanced the investigation of this archaeological context.

[1] CIDOC-CRMdig (ttp://www.ics.forth.gr/isl/index_main.php?l=e&c=656) encodes metadata about the steps and methods of production (‘provenance’) of digitisation products and digital representations such as 2D and 3D data created by various technologies, all steps and parameters from data capture down to the end-user outcome (Doërr and Theodoridou 2011; Tzompanaki et al. 2014)

Fig. 1. Fragments of statues of the Salamis collection

The partonomy was then enlarged in order to cover other kind of coroplastic productions, mainly representing human figures. The second case study included in GRAVITATE is a collection of small clay statuettes from the site of Ayia Irini (Cyprus) attributed to the Cypro-Archaic I-II periods (700-500 BC). The sanctuary of Ayia Irini was excavated by a Swedish archaeological mission (Swedish Cyprus Expedition - SCE) in 1929 and its collection, famous for its large number of terracotta artefacts of different shapes and dimensions (see Fig. 2), was divided between Sweden and Cyprus (Gjerstad et al. 1935). The majority of the artefacts were transferred to the Medelhavsmuseet in Stockholm and few groups were send to other museums in the country. The remaining part of the collection is exhibited at the Cyprus Museum in Nicosia.

Fig. 2. Statuettes from the Ayia Irini collection

A third case study has been recently added in GRAVITATE: the so called Naukratis pottery collection. Naukratis was the first Greek settlement in Egypt, on the Nile Delta. From the VII century BC Greeks and Egyptians lived together in the city, which became a trading post frequented also by Phoenicians and Cypriots. Until the foundation of Alexandria, Naukratis was the main trading port in the Western Nile Delta and continued to be significant also during the Hellenistic and Roman period. Rare Christian symbols appeared during the Byzantine period (330-641 AD) and after the VII century AD it seems that Naukratis had fallen into the oblivion. Excavations from 1884 onwards uncovered large parts of the site and a rich archaeological assemblage, much of it dedications to the town's Greek and Egyptian sanctuaries, including fine pottery imported from across the Greek world and beyond. About 18,000 findings and documentation material (e.g. correspondences, notebooks, diaries, journals) are preserved in more than 70 museums worldwide today. The collection considered in the project includes Egyptian, Greek, Roman, and Cypriot artefacts dating from the VII century BC to the VII century AD (see Fig. 3).

For this reason, a section of the partonomy dedicated to pottery is currently under development and comprises only a taxonomy of decorations and colours.

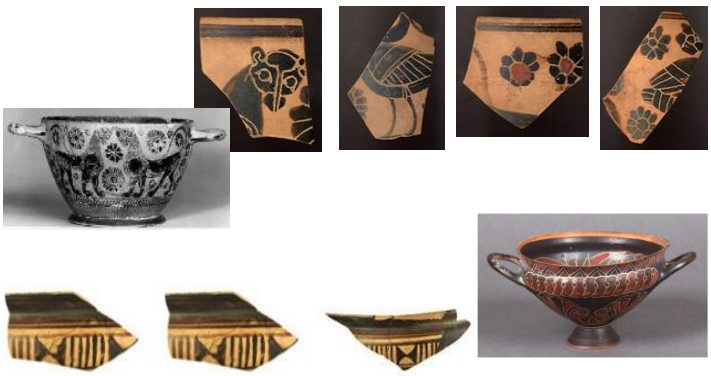

Fig. 3. Ceramic fragments from the Naukratis collection

3 State of the art

Numerous are the examples of vocabularies and taxonomies developed by various institutions and within research projects in very different domains: in art, archaeology, epigraphy (e.g. EAGLE vocabulary[2]) such tools have been developed with the major aim of serving the general frames of digital libraries and repositories (e.g. to document physical and digital items) and facilitating several activities within them (e.g. linked data).

To mention few, the British Museum (BM) uses a system of controlled terms useful to categorize and indexing the collections. The list of terms used by the BM is mainly arranged into thesaurii, structured in a hierarchical way and accompanied by variants[3]. Particularly, the most developed ones are those related to object names and materials. In this case, the theusaurus on materials defined at BM was initially "from index terms generated from computer records created using curatorial documentation and the objects themselves". After this phase, the terms were checked, incorporated into an overall hierarchical structure and successively, other relationships and features were added.

Another vocabulary widely used in the humanities domain (for digital art history and related disciplines) is the one developed by the Getty Research Institute. It is continuously extended thanks to contributions of experts and institutions. Particularly, the Art & Architecture Thesaurus (AAT) Getty[4] is a controlled vocabulary for art, architecture and other material culture. It is a faceted classification system built on terms hierarchically connected to facilitate cataloguing, retrieval, linking and research. The core set of terms started from the extraction of concepts from authority lists and domain literature, successively reviewed and expanded by experts and scholars from all relevant disciplines involved.

A more specific vocabulary dedicated to Coroplastic has been developed by the Italian Istituto Centrale per il Catalogo e la Documentazione (ICCD)[5]. Regarding the archaeological sector, the Institute created a series of vocabularies dedicated to specific material typologies: particularly, the vocabulary for Coroplastic ('RA Coroplastica') is divided into 'objects', 'subjects', and 'classes and production' (Auer et al. 1998). Also in this context, the vocabulary is created starting from real artefacts and domain literature: though, many of the terms are related to specific typologies and proper names, which are less general and point to specific type of objects (e.g. anthemion - type Andren 477).

In general, except the one developed by the ICCD, the vocabularies reviewed are not specifically oriented to coroplastic: some cover general subjects within the domain of art, architecture and archaeology as AAT Getty; some are instead oriented towards the description of the material or the technique used, such as the British Museum thesaurus; finally, others do not dwell the partonomic composition of the objects and the relations between those parts as the ICCD one.

These reasons brought us to the development of a specific list of terms that would have solved the research questions raised up by the project (see (Aaberge and Akerkar 2012). In fact, the partonomy proposed here can serve both as a vocabulary for any typical operations within a digital library and repository (search, annotation, etc.), and as for the specific aims of the GRAVITATE project (e.g. fragment re-unification). The

[2] https://www.eagle-network.eu/resources/vocabularies/
[3] https://collectionstrust.org.uk/resource/british-museum-object-names-thesaurus/
[4] http://www.getty.edu/research/tools/vocabularies/aat/
[5] http://www.iccd.beniculturali.it/

partonomy is therefore used as a support to the research allowing to subdivide and describe the artefacts into components that present hierarchical relationships between them, and to integrate the geometric and quantitative aspect to the qualitative one.

4 Cultural Heritage Artefact Partonomy

The Cultural Heritage Artefact Partonomy is a semantic description of both the body parts and the decorative features that compose the shape of the archaeological objects taken as case study. The conceptual description of the human body is formalised through the definition of each part (e.g. head, trunk, arms, legs) and their accessories (e.g. weapons, musical instruments, small animals); also the decorations on the fragments are classified.

The definition of the classes of CHAP are based on an archaeological corpus of texts (i.e. archaeological publications, catalogues, excavation reports) and on the archaeologists' knowledge. Analysing this 'unstructured'[6] material, we extracted all the terms useful to our goal (e.g. plated, beard, flower, six-petals, kid goat, flute) and then structured consistently: both general terms to identify the different parts of the human figure and specific terms indicating peculiarities of the depictions (e.g. specific elements, attributes, decorations) were included in the partonomy.

CHAP has been created in order to describe and structure formally cultural heritage artefacts, subdividing it into hierarchical components. Not only a qualitative description is supported but a quantitative one: indeed, specific attributes and relationships have been defined, able to characterise dimensionally and geometrically the different entities. Therefore, in addition to an expressive documentation of digital assets and their components, CHAP also supports computational analysis and comparison of artefacts for archaeological research.

The next subsection focuses on the partonomy itself, while the following one describes the extension of the CIDOC CRM and CRMdig schemes to associate physical and digital resources on the one hand, and to accommodate the formalisation of the geometric characterisation of digital models, on the other one.

4.1 CHAP as SKOS taxonomy

The conceptualisation is organised around few central concepts, which play an important role in the morphological and colorimetric characterisation of statues and figurines: *Body part, Attire, Decoration, Colour,* and *Technique*. The class *Generic Area* has been added to annotate a region where unclear features are present (e.g. faded colour), which would deserve additional investigation. Fig. 4 shows the general structure edited in Protégé[7] and modelled as a SKOS hierarchy in order to keep it independent of the semantic scheme.

[6] With the term "unstructured" we mean all traditional descriptions, usually available in archaeology, under form of texts, catalogues, etc.
[7] https://protege.stanford.edu/

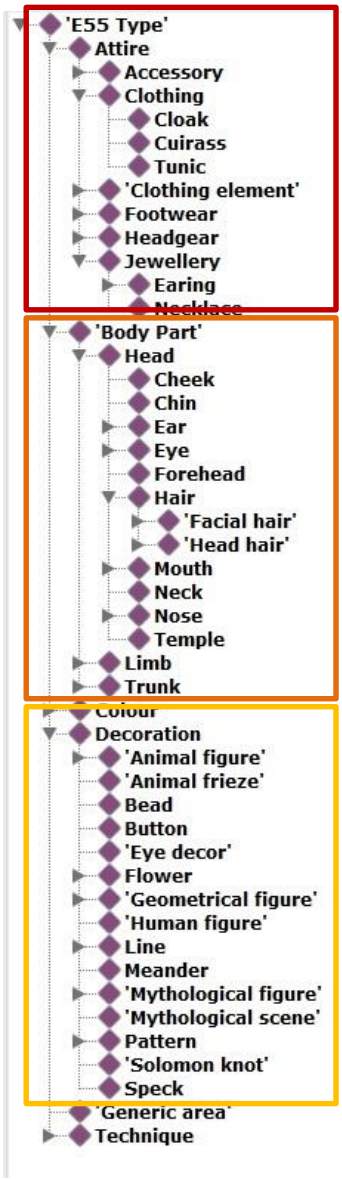

Fig. 4. An overview of CHAP

The Body part class is an extensive description of anatomical constituents, including some specific characterisations, e.g. the hairstyle and the pose of hands. In Fig. 5 the complete partonomy related to the human body is shown.

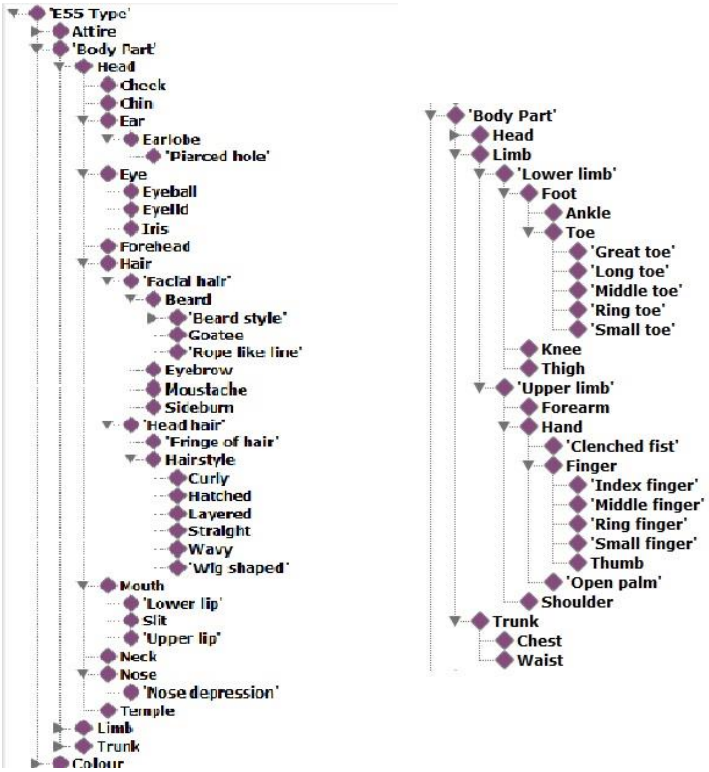

Fig. 5. On the left side, the CHAP classes related to *Head* are listed; on the right, all the other body parts are detailed.

The second key concept of the taxonomy is related to *Attire*, which classifies all the possible accessories of the figurines of the collections investigated. In Fig. 6 the pertaining excerpt is depicted. As it can be noticed, the set of accessories spans from music instruments, and weapons to elements of garment and jewellery in order to cover the features represented in the artefacts of the case studies, but also typical of other coroplastic productions.

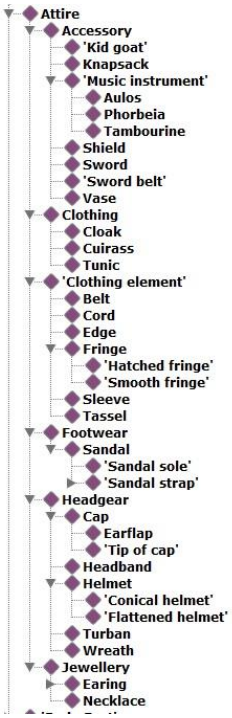

Fig. 6. CHAP classes concerning *Attire*

An extensive work has been done to analyse the fragments and catalogue reports in the datasets and classify all the decorations present in the three datasets (see Fig. 7).

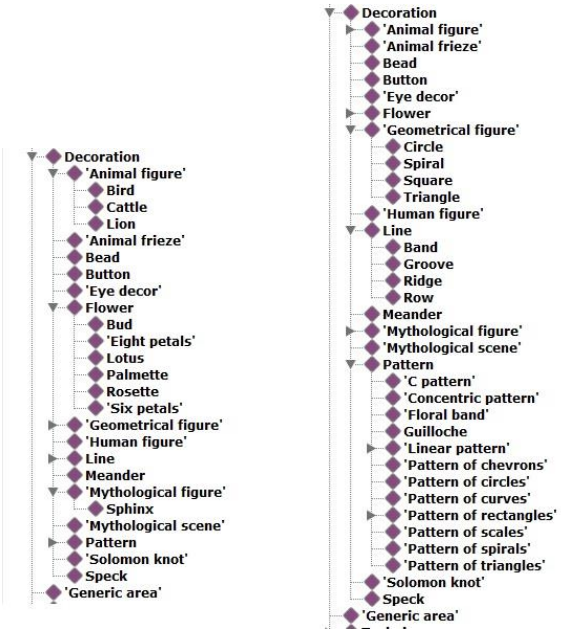

Fig. 7. (a) CHAP figurative decorations, and (b) CHAP geometric decorations

Fig. 7(a) shows the figurative decorations. It has to be highlighted that animal and human figures, and friezes are mainly peculiar to Naukratis collection, as meanders, sphinxes, and knots. We distinguished single features from the whole frieze of a scene to give the archeologist the opportunity to annotate the artefact according to his/her specific interests (i.e. single item against the entire decoration). Fig. 7(b) is focussed on geometric decorations, which may be identified and measured more easily with specific automatic algorithms. Here again, we distinguished single geometric figures, such as circles and spirals from patterns of such figures. Lines and patterns of lines are peculiar of these datasets and then exstensively represented.

Feature recognition is a well-known problem in computer graphics and many approaches have been proposed in different application contexts. Together with the feature identification, it is possible to compute some specific measures such as dimensions. CH is a particularly challenging field because of the diversity and variability of shapes; in the GRAVITATE project, (Torrente et al. 2018) devised a method for detecting and computing specific measures of feature curves, and tested it on the identification of eyes, lips and petals of the Salamis collection. The automatic recognition of geometric patterns is an ongoing research in the shape analysis community and some initial studies on CH artefacts have been carried out and discussed in (Biasotti et al. 2018) [ref]. The dimensions and specific measures of features have been added in the semantic model (see next section) and then may be used as metadata after computation.

Finally, one component of the taxonomy is devoted to colour and one to the manufacturing techniques adopted to create the artefacts of the various collections. Currently, we defined a very simplified hierarchy for both of them (see Fig. 8 for the *Technique*), which can be integrated with other recognised taxonomies, e.g. the BM thesaurus on techniques.

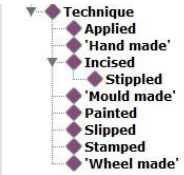

Fig. 8. CHAP classes on *Technique*

4.2 CHAP in the extended CIDOC CRM and CRMdig scheme

A key point in the proposed semantic model is the duality between the physical artefact and its digital counterpart. Indeed, the two entities are conceptually different, they may be used in different ways and with different purposes (for example, physical vs virtual museums), and then require a tailored formalisation (for instance, see Vassallo et al. in press). Nevertheless, the two concepts are tightly related as well as their characterisations and such connection should be reflected in the scheme. The semantic model presented in this work has the main objective of supporting part-based annotation of 3D digital artefacts. It is depicted in Fig. 9, which highlights the contributions with respect to CIDOC CRM (in blue) and CRMdig (in green) schemes.

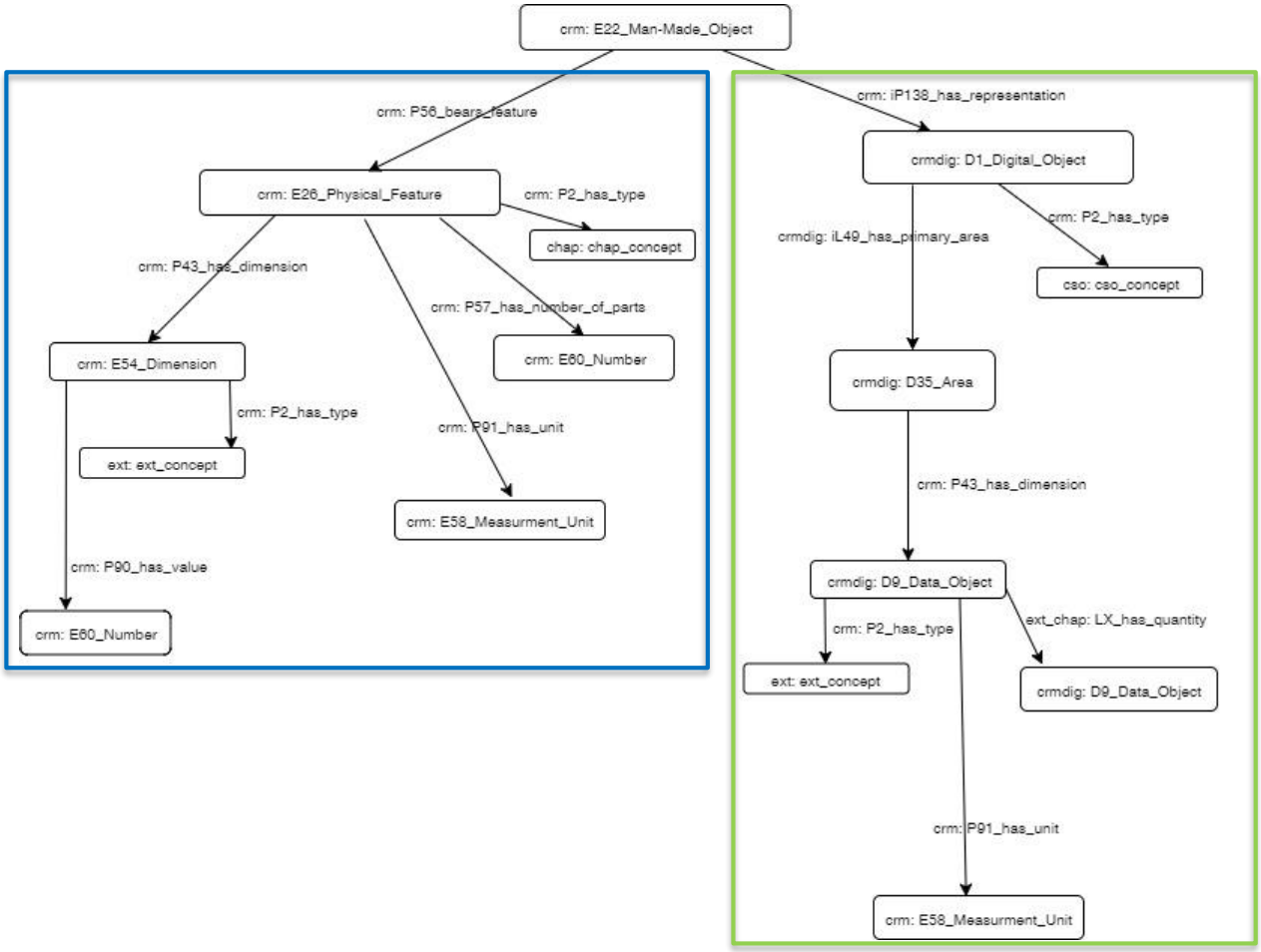

Fig. 9. The semantic model extending CIDOC CRM (in blue) and CRMdig (in green) to support 3D part-based annotation of cultural artefacts.

The extension of CIDOC CRM pertains the physical artefact and its documentation[8]. The *man-made object* (*E22*) *P56_bears_ Feature*, and *physical features (E26)* are classified according to the CHAP partonomy (modelled as a SKOS hierarchy), which is accessed by the *crm: P2_has_type* relation. As already mentioned, the specific measures of the features are formalised by the relation *crm: P43_has_dimension*, equipped with the concepts related to measure unit and type of measure. It is possible to specify the type of dimension by the *crm: P2_has_type* property and in the picture we added also a possible link to any external recognised taxonomy focussed on dimensions.

In the green box of Fig. 9, you can find the formalisation of the digital artefacts, where all the corresponding concepts have been replicated by using opportunely CRMdig concepts[9]. Here the formalisation focusses on the geometric aspects of the digital asset, so it expresses the 3D resource as a *crmdig: D1_Digital_Object* and a feature as a *crmdig: D35_Area*, since here it is represented as a digital area on the surface of the artefact. To specify the type of geometric representation used to model the digital artefact (e.g. triangular

[8] Cfr. http://www.cidoc-crm.org/versions-of-the-cidoc-crm
[9] Cfr. https://www.ics.forth.gr/isl/index_main.php?l=e&c=656

mesh), a reference to an existing taxonomy can be used: in our scheme we considered the Common Shape Ontology (CSO), whose objective was to formalise the geometric representations commonly adopted in computer graphics and computer vision (Vasilakis et al. 2010).

While on the physical side dimensions usually correspond to numbers (e.g. length, depth, volume), there are many different measures that can be computed on a digital model. Therefore, it has been necessary to extend the CRM concept of *Dimension (E54)* to the *crmdig: D9_Data_Object*, which includes any kind of digital measurement of the data. An example of measurement is the computation of the mean curvature on the surface: the result is a scalar map, that is a value of curvature for each vertex of the mesh. This kind of computation has to be represented as a more elaborated concept, i.e. as *crmdig: D9_Data_Object*, Besides, it requires also an additional relation, which is not present in the CRMdig scheme: we named *ext_chap: LX_has_quantity*, and allows to connect the computation of any complex geometric characterisation (such as mean curvature) to a digital area of the 3D model. A suitable external taxonomy concerning digital computations on 3D models may be linked to the scheme to document the available geometric characterisations of the model and its features.

It has to be noticed that the set of computations on digital artefacts is in principle larger than on the physical ones: then, it has been necessary to define an *ad hoc* conceptual model, which allows the user to access such information and use it for quantitative analyses of artefacts.

5 CHAP in use

The primary goal of the proposed semantic model is the part-based annotation of 3D artefacts serving data retrieval in archaeological research. In particular, experts would be able to prove or disprove research hypotheses with the aid of geometrical reasoning and comparisons on digital artefacts. On the one hand, an appropriate knowledge-based system should set up; on the other hand, morphological and colorimetric characterisations would definitely benefit from a digital platform able to visualise, analyse and annotate 3D models.

The Dashboard is the front-end of the GRAVITATE platform, aimed at processing, analysing and documenting cultural assets (Catalano et al. 2017). It proves the value of the combination and integration of several shape and semantic tools, providing web and desktop functionalities. The web client is devoted to semantic modelling and search, while the desktop client addresses 3D high-resolution digital resources. In Figs. 10-12, we show different tools to support analysis and annotation in the platform. In Fig. 10, the Inspection view is illustrated. It includes the parallel visualisation of 3D models and geometric properties: the archaeologist is able to zoom in and out the models, compare catalogue metadata and visualise properties and previous annotations on the selected models.

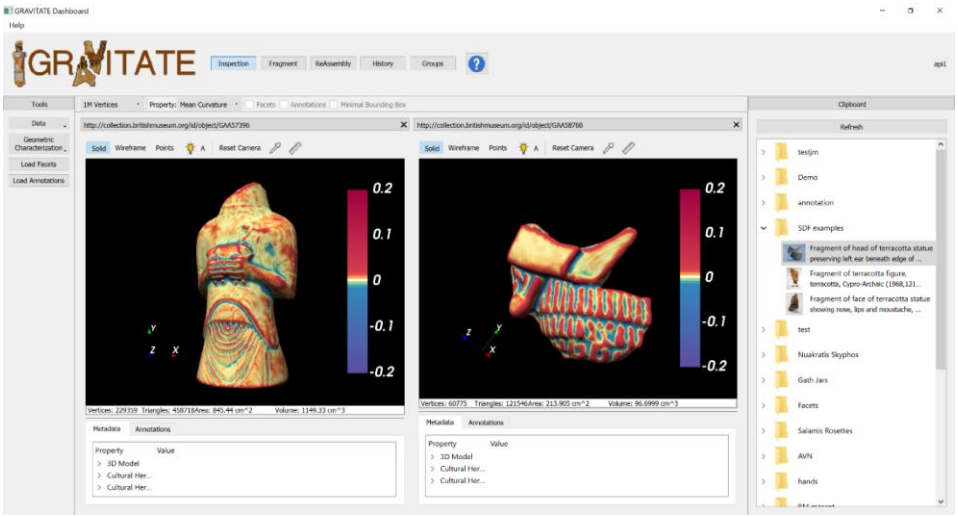

Fig. 10. Parallel visualisation of the mean curvature on two different fragments in the GRAVITATE platform.

In Figure 11, an example of automatic recognition of eyes on a Salamis fragment is given, where some significant measures pertaining eyes (the two major axes, in this case) are also displayed in the 3D canvas.

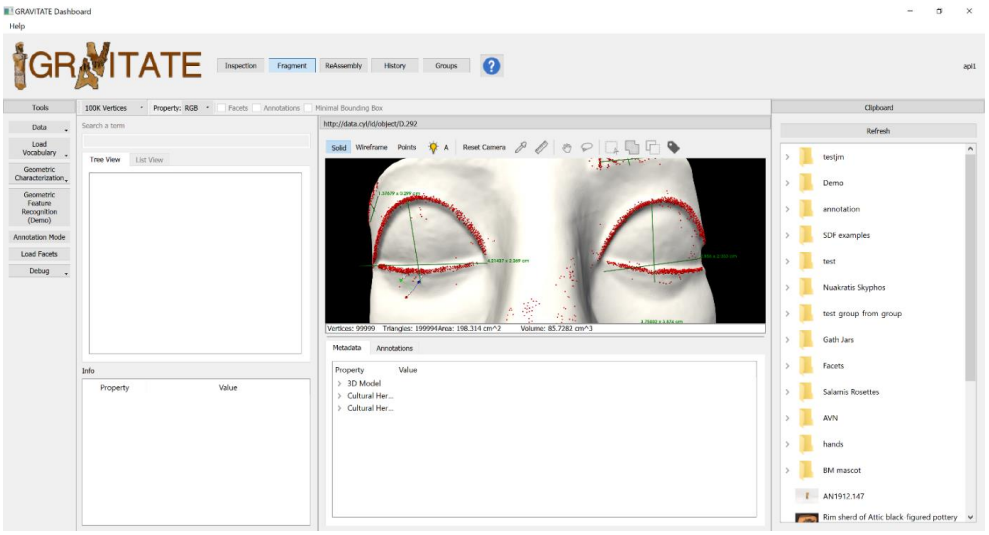

Fig. 11. Feature recognition demo in the GRAVITATE platform.

Once a feature has been automatically identified, the successive operation of annotating the model together with its measures according to the scheme described in Section 4 becomes simple in the dashboard. In the current implementation, it is not possible to annotate directly after the feature identification, but the area to be annotated has to be selected manually by the user. In Fig. 12, the annotation mode is shown: the CHAP is displayed on the left, the central 3D canvas includes tools for the manual selection of digital areas, and the box at the bottom shows all the annotated areas.

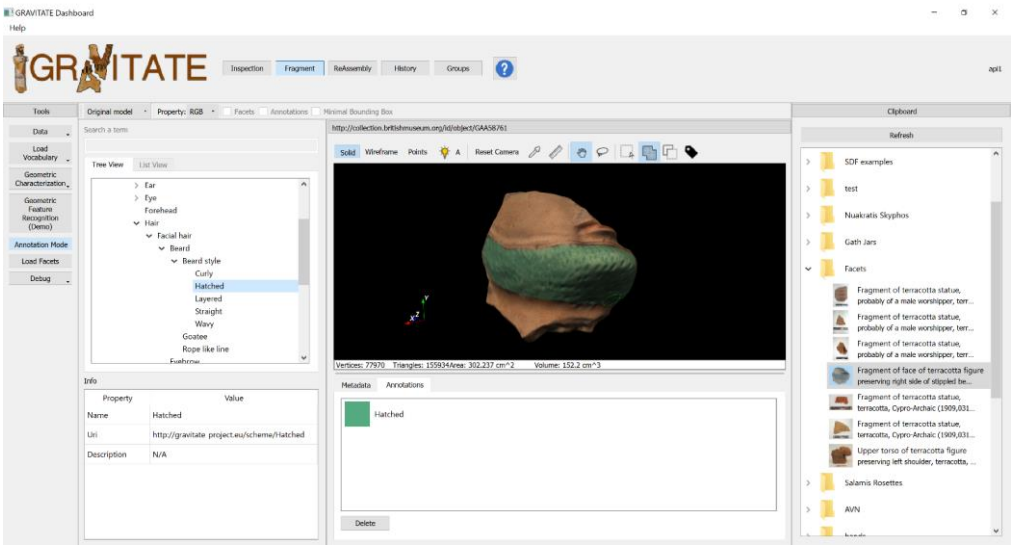

Fig. 12. 3D part-based annotation of a "Hatched beard" on a 3D artefact in the GRAVITATE platform.

Annotations are saved in the knowledge base with qualitative and quantitative data on the artefacts, and can be retrieved using traditional queries as in all knowledge-based systems.

6 Conclusions

The article presents an approach and a semantic scheme to document part-whole relationships of cultural artefacts within the scope of 3D objects. The proposed scheme is based on CIDOC CRM and CRMdig and is able to accommodate features and measurements; CHAP has been also defined, a SKOS vocabulary concerning two

specific archaeological uses cases on coroplastic Cypriot art. The archaeological goal is to create a partonomy that will be useful to describe a wider coroplastic production of Cyprus in the future.
In the current state, CHAP addresses the Salamis and Ayia Irini collections studied in the project. Nevertheless, the structure of the partonomy has been conceived to be extended to other coroplastic representations and/or specific chronological periods, geographical areas, and so forth. Indeed, the formalisation of fragments coming from the Naukratis ceramic collection has already started. Indeed, various SKOS taxonomies may be added to the scheme, by means of the *P2_has-type property*, which permits to classify objects and object features.

Moreover, the CIDOC CRM and CRMdig extensions proposed here are more general than they appear at the first glance. First, the semantic scheme is customisable and extendible to any other archaeological context, whenever the goal is an extensive digital documentation of tangible finds. Second and even more important, the major contribution of this work relies in the extension of the CIDOC schemes in order to support the semantic annotation with quantitative attributes. This is a general approach, which paves the road to innovative methodologies to carry out research on 3D digital tangible heritage.

Future work includes enlarging the scope of this work completing CHAP and the extended semantic scheme with other relevant taxonomies and schemes, related both to the archaeological context and to the digital and computational measures suitable for those contexts.

Acknowledgements

This paper has been supported by the H2020 EU project GRAVITATE "Geometric Reconstruction And noVel semantic reunificaTion of culturAl heriTage objEcts", Grant Agreement n. 665155. All the 3D models belong to the Salamis collection maintained in the STARC repository of the Cyprus Institute.

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