

# An automatic approach for the classification of ancient clay statuettes based on heads features recognition

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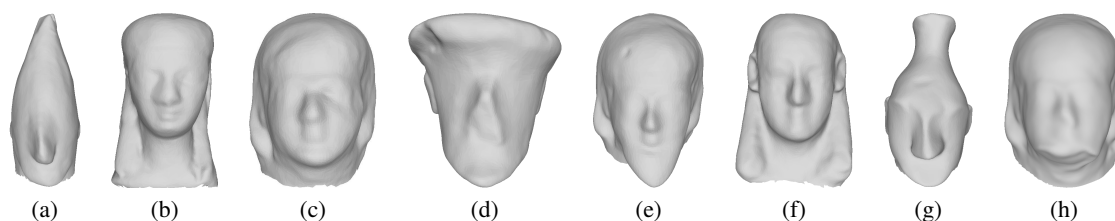


Figure 1: Some artefacts of the dataset

## Abstract

In recent years, quantitative approaches based on mathematical theories and ICT tools, known under the terms of digital, computational, and virtual archaeology, are more and more involved in the traditional archaeological research. In this paper, we apply shape analysis techniques to 3D digital replicas of archaeological findings to support their interpretation. In particular, our study focuses on a collection of small terracotta figurines from the ancient sanctuary of Ayia Irini, Cyprus, and it aims at re-analysing the material utilising a quantitative approach. We experiment state of the art techniques (meshSIFT and DBSCAN) to cluster statuettes according to the similarity of their heads, to investigate their production process.

## CCS Concepts

• **Computing methodologies** → Shape analysis; Mesh geometry models; Shape representations; • **Information systems** → Clustering and classification; • **Applied computing** → Archaeology;

## 1. Introduction

In archaeology, classification, systematic arrangement and grouping come from the necessity of the scholars to order, interpret and date the archaeological dataset under study. Traditionally, archaeologists create such groups operating qualitative choices. In this contribution, we apply shape analysis techniques on 3D digital replicas of archaeological findings to support their classification. In particular, our study is applied to a collection of small terracotta figurines from the ancient sanctuary of Ayia Irini, Cyprus [GLSW35], and it aims at re-analysing the material utilising a quantitative approach [Vas16, Vas17, SVM\*18] to complement the previous results with traditional methods on the same material [GLSW35].

The Ayia Irini collection consists of almost 2000 votive clay statues and statuettes of different size, shape, and style found in an ancient Cypriot sanctuary. The site was brought to light by a small

group of Swedish archaeologists in the 20th century [GLSW35]. The collection includes medium and large human statues (man-size and over), animals, minotaurs, horsemen, etc. The material was classified by the Swedish archaeologists into 16 typological groups according to qualitative and stylistic criteria. Just after the excavation, the artefacts were divided between Sweden and Cyprus, and they are currently conserved in five different museums: the contemporary setting complicates the possibility to study the material in a complete, holistic, and coherent way. For this reason, 103 statuettes from the different hosting institutions and belonging to the so-called 'small human idols', have been chosen and digitised, both through laser scanning and photogrammetric technique, in order to produce 3D replicas to be quantitatively analysed. The sampled items belong to three of the 16 typological groups [GLSW35, pp. 785-790]: Type 5, 6, and 7. Type 5 and 6 comprehend the 60 hand-made statuettes of the sample, sharing similar characteristics

that resulted in a not-always-definite attribution to a class respect to another [Kar95, p. 5]. The 43 statuettes of the sample attributed to Type 7, instead, share more defined characteristics, due to the tools and techniques employed: wheel for the bodies and moulds for the heads (only the arms and some added features are produced by hands). Moreover, the archaeologists state that for the Type 7 statuettes 5 moulds were used to produce their heads *but no attribution of how many and which statuettes correspond to each mould was done* [Fou07, pp. 89-92, 127-132]. Also, some similar features of the hand-made heads suggest a possible same artisan's production.

The 3D analysis in this study aims at quantitatively test these hypotheses and answer the following archaeological questions. Can we quantitatively measure characteristics in the hand-made heads that help us to identify a production by the same artisan? How many moulds can be identified in our sample? How many and which artefacts come from the same mould?

## 2. Pipeline of the approach

In our experiments, we focus on the statuettes' heads and their mutual similarity to group figurines whose heads are most similar. Each class should possibly represent figurines created by the same hand or produced with the same mould. We proceed as follows: firstly, we extract the head part from the mesh of the whole figure. Then, we exploit two state-of-the-art algorithms to i) assess the similarity among faces and ii) cluster similar faces into classes. In this preliminary work, we manually segmented heads using MeshLab [CCC\*08]. Any mesh defect (e.g., isolated vertices, duplicated faces) were fixed using MeshLab and ReMesh [AF06]. Since apparently the moulds consisted only of a front half, the head back may bias the comparison. Therefore we also extract faces for Type 7 by removing the head back using MeshLab.

### 2.1. Similarity assessment

We apply MeshSIFT to assess the similarity between pairs of head meshes. MeshSIFT was first introduced by Smeets et al. in 2013 for expression-invariant face recognition [SKDP13]. Albeit the invariance to face expression is not a requirement in our setting, we employ this method because it is robust to incomplete data (heads and faces are represented as open meshes). Moreover, the method has proven to achieve a good recognition rate in international recognition contests like the "SHREC '11: Face Scans" [VJD\*11]; an open implementation in Matlab is available online [CDJF19]. In brief, MeshSIFT computes correspondences between salient points on the two meshes, the number of matched pairs being the estimate for how similar the two meshes are (we refer to the original article for details).

Comparing  $n$  heads in pairs produces a  $n \times n$  matrix  $M$  of integers such that  $M_{i,j}$  contains the similarity value  $s_{ij}$  between face  $i$  and face  $j$ . The maximum values by row and by column lay on the diagonal (self-similarity). The range of similarity values for each head/face differs a lot: in our experiments, the self-similarity value ranged between 1466 for the model with inventory A.I.1249 and 160 for A.I.1295. Furthermore, the clustering algorithm we employed for the next step needs distances among elements rather

than similarities. Therefore, the similarity scores for each model (with the maximum being the self-similarity value) are normalised in the range  $[0, 1]$ ; then, data are reversed to represent the distance between two heads as  $d_{ij} = 1 - s_{ij}$ .

### 2.2. Head clustering

To cluster heads based on their normalised distance we apply DBSCAN [EK SX96] to the first three components of the eigenvectors extracted from  $M$  (this triplet being also used as coordinates to plot heads in the score space). DBSCAN is available from Matlab R2019a and is one of the most used and cited clustering methods; it is designed to discover clusters of arbitrary shape in noisy applications. We refer to the original article for details.

DBSCAN requires two parameters: the minimum number of points to define a cluster (set to 1) and the value of the threshold  $\epsilon$ , which relates to the density of clusters and affects the clustering granularity. Higher values of  $\epsilon$  determine few, huge clusters; conversely, a smaller  $\epsilon$  will produce more, smaller sets. If  $\epsilon$  is not set, the algorithm self-estimates this parameter.

We tested different values for  $\epsilon$ . Since values are normalised in the range  $[0, 1]$ , we arbitrarily imposed that the maximum distance between points in the same cluster should be below the 10% of the maximum distance (so 0.1). A sort of *average distance* inside the clusters was also used, evaluated by extracting the  $k$  nearest neighbours (where  $k$  is the expected size of the cluster) for each point and then computing the average of the mean distance between them. We used the knn-search algorithm provided in [FBF77] and available on Matlab. In the following, we will refer to this value as  $knn-\epsilon$ . Finally, the self-calculated  $\epsilon$  provided by DBSCAN was also used. However, in the different experiments we noticed that the 0.1 and DBSCAN chosen threshold does not always give good results, so in the following we will present the results achieved using the  $knn-\epsilon$  threshold.

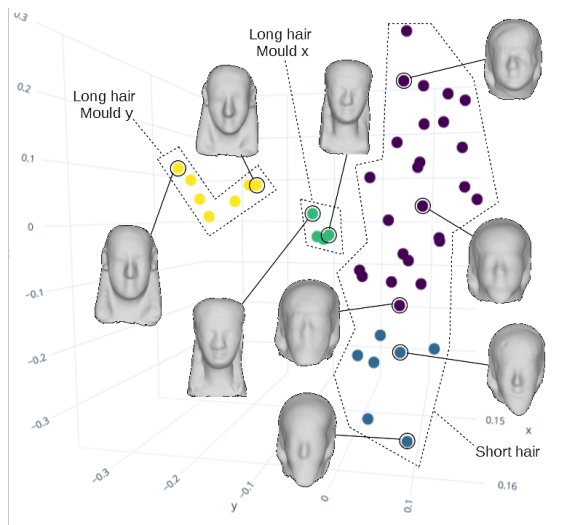
## 3. Experiments

We performed three experiments to analyse and interpret the manufacturing of the statuettes for classification purposes. We first analysed separately moulded and hand-made heads, and finally the whole set.

### 3.1. Intra-class clustering: moulded faces

In the first experiment, we focused on the 43 moulded heads of the Type 7 statuettes to estimate how many moulds were used for their production and which statuettes were produced with each mould. In this test only faces were taken into account.

The clustering highlights two main classes, namely #1 "*short hair*" and #2 "*long hair*" heads, according to their most apparent characteristic. Also, though testing different values of  $\epsilon$ , we note the stable and constant presence of two separate and well definite clusters within the "*long hair*" heads group. With reference to Figure 2, using  $knn-\epsilon$  as threshold highlights two subgroups (in yellow and parakeet) in the "*long hair*" class, and other two (in aegean and violet) in the "*short hair*" class. The result suggests that the "*long*



**Figure 2:** The results of the clustering (using the  $knn-\epsilon$  threshold) of all the moulded faces

hair" heads might come from two different moulds, while the "short hair" heads appear very close to each other, suggesting a production from the same mould but, at the same time, with a distinction.

Indeed, 13 heads out of the 32 in the "short hair" class show a small piece of clay representing a beard, manually added after moulding.

We noticed that at finer clustering levels (i.e., at smaller values of  $\epsilon$ ) the subdivision between "heads with beard" and "heads without beard" within the "short hair" class emerges, but two sub-classes are not always precisely delineated, possibly because the added handmade beards bias the comparison.

Therefore, we repeated the experiment on the "short hair" subset with three different settings:

- analysing only the 18 faces that have no added beards ("heads without beards");
- analysing all the 32 faces after manually removing the beards from the 14 ("heads with beard");
- analysing all the 32 faces after manually removing the beards from the 14 "heads with beard" and the chin from the 18 "heads without beard"

The first experiment was done to check if any subdivision within the "short hair" faces "without beard" appeared. With  $knn-\epsilon$  threshold, one main group was created, with only three external items. Only a further quantitative comparison among the faces could clarify if these deviations, rather than indicating different moulds, could be due to mould degradation, different pressure on the clay, or degradation of the artefacts.

The aim of the second experiment was to check if any new clustering could have been identified. The results show a definite subdivision between faces "without beard" and faces once "with beard". The reason could be that modified faces present a lack and therefore the recognition happened only on the superior part, creating a

group *per se*. So, we repeat the test eliminating the chin, bearded or not, from the 32 faces, to make the group homogeneous.

The third experiment produced a big group with some small other clusters, which can be possibly introduced by the erosion and/or by different pressure on the material during the production.

### 3.2. Intra-class clustering: handmade heads

We tested the same approach on the 60 handmade statuettes (Types 5 and 6). They are a lot more troublesome, principally because of the peculiarities induced by the mere use of the hands for production. In this case, we do not restrict to the face front but, conversely, we analyse the whole head mesh, since the artefact is entirely handmade. As mentioned, this group is characterised by a range of different features: "long hat" (Figure 1(a)), "short hat", "truncated hat" (Figure 1(g)), "turban hat" (Figure 1(d)), and so forth, terms used by the archaeologists just to describe them qualitatively and therefore in a subjective and not homogeneous way. Changing the value of  $\epsilon$  during the experiment, it appears that certain subgroups are stable, such as the one composed of statuettes with "long hat" heads, with "short hat" heads or the one represented by statuettes with "truncated hat" heads. The latter group is particularly interesting for the interpretation of the production of the statuettes: a parallel investigation on the same material showed the identification of traces of the very same type of decoration and pigments, suggesting a probable production by the same hand [VGH].

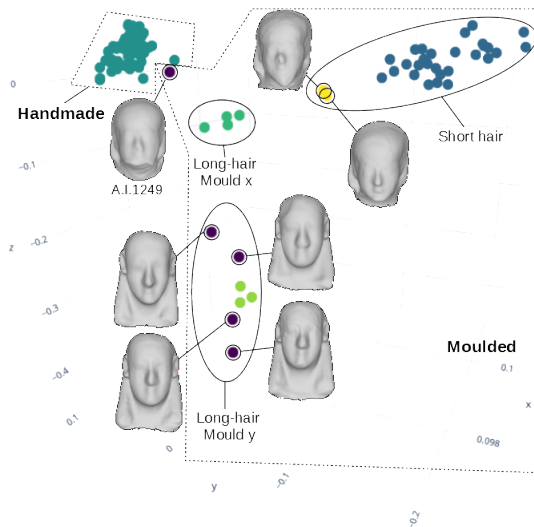
### 3.3. Inter-class clustering

The aim of this last experiment was, firstly, to understand if our procedure is able to guess the classification of the heads into handmade and moulded and, secondly, to test whether other interesting information (i.e., a new classification) could be extracted from the whole dataset. Since the handmade heads are analysed integrally, we use the entire head for the moulded elements as well. The unsupervised analysis indeed shows the principal subdivision of the artefacts between moulded and handmade statuettes according to their production technique (Figure 3, where the handmade are the teal ones and the wheel made the remaining). Moreover, previous tests identified the presence, within moulded statuettes, of a "short hair" (aegean and yellow) and a "long hair" subgroups (lime and parakeet), and at least two possible moulds, x and y in the "long hair" heads. It is worth to note that the group of heads created with the hypothetical mould y could be still divided in two further parts (the lime dots represent the heads produced with the mould y, while other points here demarked as outliers - violet - should be part of the same group). In the future, we will further analyse these artefacts.

## 4. Conclusions

In this paper, we presented an experimentation using state of the art techniques to preliminary investigate the potential of quantitative analysis to support the interpretation and classification of the Ayia Irini collection.

Following the analyses presented in this paper, we can quantitatively identify three different moulds in our sample: one for the



**Figure 3:** Results of the clustering (using the  $knn-\epsilon$  threshold) on the whole dataset

"short hair" and two for the "long hair" heads. For the "short hair" faces, the addition of handmade features (e.g., beards) complicates the recognition. We are inclined to affirm the use of one mould for the production of this group, with the presence of slight differences probably due to the degradation of the artefacts or different pressure on the clay. Additional quantitative analyses could possibly provide further information to confirm or refute the hypothesis. The analysis carried out within the moulded faces (Type 7) highlighted the presence and use of two different moulds for the creation of the "long hair" statuettes (used for four and seven statuettes, respectively). However, we have no sufficient elements to confirm nor contradict the use of five different moulds for the production of the Type 7 heads, as suggested by the archaeologists who studied the Ayia Irini material. A further study on all the artefacts attributed to Type 7 as well as the insertion of all the statuettes counted in the "small human idols", could provide more information about the production and provenance of this material. This initial work has limitations: firstly, we did preliminary tests using popular state of the art tools, but it is likely that more suitable approaches exist that match the requirements of this setting: for instance, we don't require the expression-invariance that meshSIFT provides. The shape analysis literature is rich of different schemes that can overcome the proposed results [SBW17, ZX18]. In future improvements, we will also investigate if an optimal DBSCAN threshold can be defined, or if a finer distance metric can provide more discriminate results.

### Acknowledgements

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