# Towards a System for Semantic Image-Based 3D Documentation of Archaeological Trenches

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**Abstract:**
*Archaeological trenches are mostly documented using 2D representations like hand-made or computer-aided (CAD) drawings, photographs and rectified photographs. On the other hand computer vision techniques and range scanners become more and more popular for producing 3D models of archaeological sites. However, these models alone provide no information about the contained archaeological entities of the reconstructed trench. In this work, an algorithm is proposed which uses the semantics "encoded" in 2D CAD drawings to perform a semantic classification of 3D models. The result is a set of segments of the 3D model which corresponds to the semantic entities defined by the polygons in the drawing. Noise, misregistrations and ambiguities (due to the lower dimensionality of the CAD drawing) are dealt with by finding connected segments in the model based on surface normals.*

**Key Words:** *3D Documentation, Semantic Classification, Segmentation, Virtual Archaeology*

## Introduction

A variety of techniques is used for documenting archaeological trenches and the changes they face throughout the progress of an excavation. Much time and effort needs to be spent for this task, because the interpretation of the configuration of the finds and features is usually carried out in retrospect after the excavation. Hand-made or computer-aided drawing (using CAD or GIS software), photography and image rectification are the most important techniques to accomplish this task. All these methods have in common that they produce only 2D representations of a trench (Fig. 1).

On the other hand computer vision techniques (Pollefeys et al. 2004, Remondino and El-Hakim 2006) and laser scanners have become very popular for producing 3D models of archaeological sites (Cosmas et al. 2001, Wulff et al. 2009). 3D models not only allow for more intuitive representations of trenches, they also enable measuring in 3D space (Wulff et al. 2010) and correlating the models with other spatial data. However, 3D models alone represent only the surface geometry and provide no information about the archaeological entities contained in a trench. To get a semantically enriched model it is necessary to further process the 3D data.

Allen et al. (2004) presented a modelling pipeline for visualising archaeological sites in 3D. They augment 3D models with context information, namely GIS data surveyed at the site. This information is displayed additionally to the 3D surface geometry – the model itself is not classified in any way.

*Figure 1. Common documentation techniques for archaeological trenches. Top left: photo of a trench, top right: a rectified photograph approximating an ortho-projection, bottom: CAD drawing as an abstract representation (created by Luise Lorenz and Julia Kunze, University of Kiel).*

Manferdini and Remondino (2010) focus on architectural finds and use 3D modelling software to classify 3D models by hand. The 3D modelling software aids in this process by providing automatic procedures for selecting and grouping faces using constraints such as inclination of adjacent faces, lighting or shading values.

The method proposed in this paper is intended for the semantic classification of 3D models of archaeological trenches. To reduce the need for user interaction it aims at utilizing CAD drawings which are already part of the documentation procedure. Such CAD drawings hold information about the semantic entities contained in a trench and are reused for the semantic classification. The basic idea is to project each triangle of the reconstructed 3D geometry into the CAD drawing to determine to which archaeological entity it belongs. Problems arising at perpendicular surfaces are dealt with explicitly by considering surface normals.

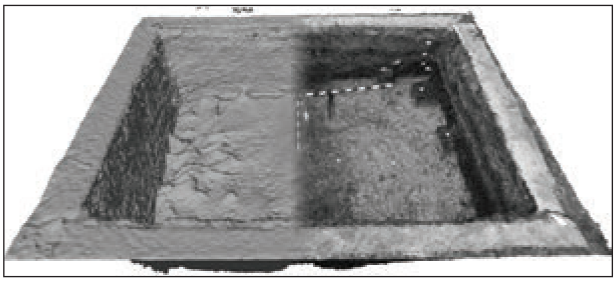

*Figure 2. The reconstructed 3D model of a trench. The left side shows the untextured geometry and the right side the textured model.*

The structure of this paper is as follows: section 2 describes the input data for the algorithm and how it can be acquired. The proposed algorithm for the semantic classification is presented in section 3. The paper is concluded in section 4.

## Data Acquisition

A variety of techniques can be used to create a 3D model of an archaeological trench, e.g. laser scanners, structured light, and computer vision („structure-from-motion“). In this project computer vision techniques are used to perform an image-based 3D scene reconstruction. Though the accuracy of laser scanners and structured light is in general higher than of computer vision techniques, structure-from-motion requires only equipment that is already part of the archaeological documentation procedure, namely a digital camera.

Besides that, a total station is used to measure a set of points in the scene. With these points it is possible to transform the model into the reference coordinate system used at the excavation site (Horn 1987). This allows for measuring in the model and correlating it with other spatial data.

The 3D geometry is finally clipped to a bounding box encompassing only the relevant parts. Since the model resides in the reference coordinate system from the site, the bounding box can be specified intuitively in the site’s coordinates. A reconstructed 3D model is shown in (Fig. 2).

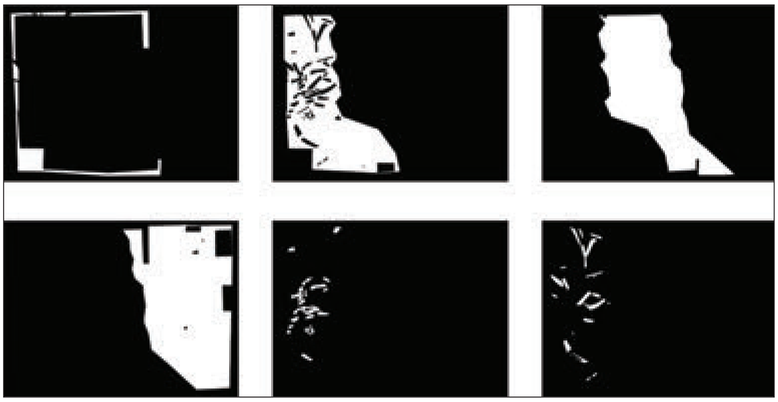

*Figure 3. Examples for classification masks. The masks are used for the image-based classification and determine if the area covered by a certain pixel belongs to a semantic entity (white) or not (black).*

The CAD drawing used for the classification is created directly on site using a total station and CAD software (Fig. 1). Since both, the model and the CAD drawing, reside in the site's coordinate system, they can be correlated with each other. The CAD plan forms the basis for the semantic classification as the boundaries of the semantic entities are created according to the shape boundaries in the CAD drawing. A high precision is therefore crucial.

## Semantic Classification

Classifying a 3D model semantically closes the gap between recent methods for 3D documentation and conventional 2D documentation techniques. While textured 3D models can provide realistic representations of archaeological trenches, CAD plans have the advantage of giving an abstract overview of the configuration of the finds and features contained in a trench. Using the proposed method, it becomes possible to directly switch between natural and abstract representations in 3D space.

The goal of the semantic classification is to classify each triangle of the reconstructed geometry and to assign it to an archaeological entity, i.e. a certain find or feature. The classification is performed automatically by reusing the CAD drawing which documents the archaeological entities contained in the trench.

### *Preparations*

The first step is to create *classification masks* from the CAD drawing. These masks are binary images created for each entity in the CAD drawing. A pixel is coloured white in the masks if its covered area belongs to the corresponding semantic entity. Otherwise it is coloured black. See figure 3 for some examples. Since the CAD drawing resides in the site's coordinate system, it is possible to compute translation, rotation and scale between the CAD drawing and the classification masks image coordinate system. This allows computing the transformation between the 3D model and the classification masks.

The basic idea of the classification algorithm is to project each triangle of the layer into the classification masks. The triangle is then classified according to which class was hit by at least two of its projected vertices. Figure 4 visualises this idea. As the figure shows, problems may arise at surfaces perpendicular to the $x$-$y$ plane caused by registration errors, ambiguities due to the lower dimensionality of the CAD drawing and inaccurate drawing. The falsely classified triangles basically fall into two categories and can be addressed by the following strategies:

Triangles from the profiles (the boundaries of the trench) extend into the area covered by the CAD drawing and are therefore classified as being part of the layer. This can be avoided by

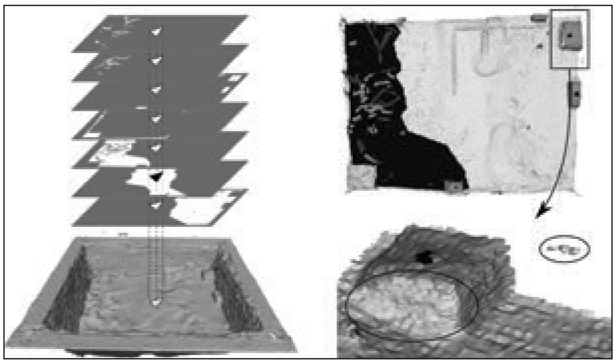

*Figure 4. The classification masks are used to perform the classification image-based. Left: Each triangle of the 3D model is projected into the classification masks. The triangle is then assigned to the class which is hit by at least two of its vertices (marked in black). Right top: Result of the naive classification. Right bottom: Close-up view of the top right area of the classified model. Problems arise at perpendicular surfaces. Alignment errors cause falsely classified triangles at protruding objects and at the trench boundaries (marked with ellipses).*

removing irrelevant parts from the geometry before the classification is performed. All areas not documented in the CAD drawing are irrelevant in this sense.

Triangles from the perpendicular boundaries of protruding objects (e.g. sockets) jut out of the class boundaries. This problem is addressed by explicitly assigning triangles from the boundaries of a protruding object to the same class as the triangles of its top-most area. Details for these two strategies are described below in more detail.

### *Removing irrelevant parts*

Removing irrelevant parts is achieved by first finding the profiles (trench boundaries) in the model. Usually the trench profiles are aligned with the axes of the site's coordinate system. This observation can be exploited by sorting all triangles into a histogram according to their normals. The histogram consists of 6 bins for the three coordinate axes and the two directions of each axis, i.e. POS_X, NEG_X, POS_Y, NEG_Y, POS_Z and NEG_Z. The normals of the triangles are smoothed within a small geodesic window to better compensate for noise. Neighbouring triangles in the histogram bins are then combined, so that connected model parts with similar normals form up connected segments (Fig. 5). For each of the segments an average normal is computed. The profiles can then be found be searching for the biggest connected segments in the bins POS_X, NEG_X, POS_Y and NEG_Y, respectively. In case of very noisy models or uneven profile surfaces triangles belonging to a profile may still be missed (Fig. 6). Therefore, small segments (with the number of triangles below a threshold) within a certain distance to the profile's bounding box are added to the profile segment. The triangles of the profiles can now be labelled according to which profile they belong to. Afterwards these parts are removed from the model as they are irrelevant for further computations. This effectively splits the model into a set of unconnected segments. Only the biggest one is considered from now on, as this belongs to the layer (Fig. 7).

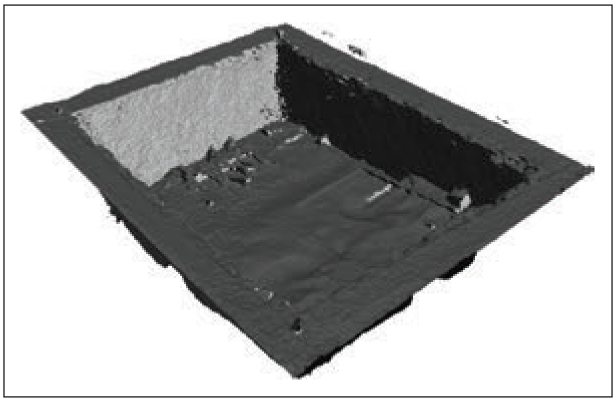

*Figure 5. Connected segments with similar normals are grouped together by performing a histogram-based segmentation. Each triangle is added to a six-bin histogram according to its smoothed normal. Neighbouring triangles in the same bin are grouped together to form up a segment.*

Now the classification is performed only on the

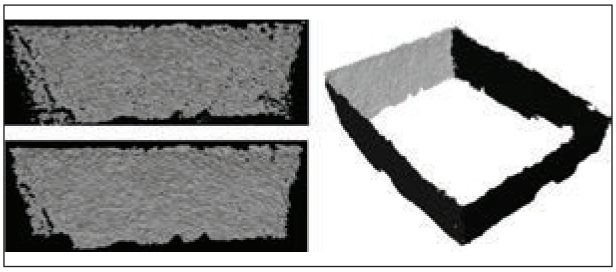

*Figure 6. Left top: Small segments may be missed in the histogram-based segmentation due to noisy and uneven surfaces. Left bottom: Small segments within a certain distance to the bounding box of a profile have been added to that profile. Right: The final segmentation of the profiles.*

relevant part of the model as described above i.e. the triangles are classified by projecting them into the classification masks. As mentioned before, triangles at perpendicular boundaries of protruding objects may be classified falsely due to errors and ambiguities (Fig. 4). They are refined as described in the next section.

### *Refinement of protruding objects*

To refine the model at the perpendicular surfaces of protruding objects, the user specifies which classes represent protruding objects (e.g. sockets). The segments based on the normal histogram are then considered again for the refinement. First, neighbourhood relationships between all segments are determined. These are modelled as a graph. Then, segments with an average normal lying in the *x-y* plane (perpendicular to the up direction) are searched. For each of these segments its neighbours are considered. If one segment has a neighbour with an average normal pointing upwards and its centre of mass lying above its own one, it is added to the semantic class of that neighbour (Fig. 8).

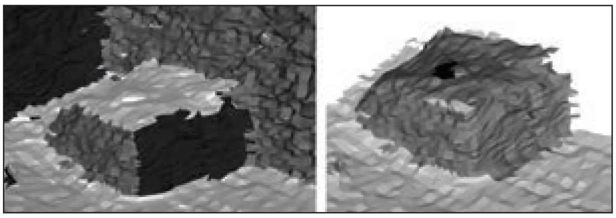

*Figure 8. Left: Detail view of the histogram-based segmentation. For each protruding object its perpendicular boundaries are searched. Each of these segments is then added to the class of the top-most area of the object. Right: Refined socket. Compare the result to the unrefined socket in figure 4.*

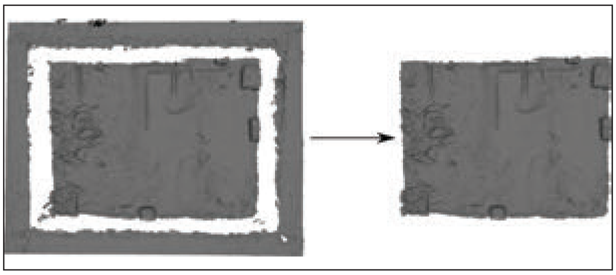

*Figure 7. Finding relevant parts. Left: Removing the profiles from the original geometry splits the model apart. Right: Only the biggest part is considered for the classification as this is the layer of the trench.*

Finally, each triangle is labelled according to the semantic class it is assigned to. Based on this labelling one triangle mesh is created for each class, so that single parts of the model can be shown or hidden according to the user's choice. Figure 9 shows the final result.

*Figure 9. The resulting semantic classification. The layer is classified into the entities contained in the CAD drawing. Additionally, the profiles (which are semantic entities too) are segmented based on the surface normals.*

## Conclusions

In this paper a classification algorithm was presented which classifies a 3D model of an archaeological trench into semantic entities. The entities are defined by a CAD drawing representing the trench as a 2D orthoprojection. Such drawings are part of the trench documentation procedure and are reused in this approach. This minimizes the need for user interaction which is required for a manual classification.

For the future, the restriction that the profiles need to be aligned with the coordinate axes is planned to be removed. Though this assumption is true at most sites, in some cases the algorithm might be unusable. Therefore clustering algorithms that are invariant against rotation will be investigated. This might also improve the robustness against missed triangles.

Furthermore, the quality of the classification needs to be improved. Especially at ridges the features boundaries do not always coincide with the geometry as expected. In this context an automatic detection of protruding objects would be desirable too.

The feature boundaries always coincide with the edges of triangles. If the model has a low resolution the deviation between the feature boundaries in the CAD drawing and in the 3D model might be significant. This problem can be faced by subdividing triangles that cross the boundaries according to the polygons in the CAD drawing i.e. by adaptively increasing the resolution near feature boundaries.

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