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3D Models of Architectural Remains in Archaeological Context: Visualisation as a Tool in Interdisciplinary Research of the Polish Archaeological Mission in Kato Paphos on Cyprus

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Abstract

The aim of the paper is to present the usage of different methods for obtaining 3D virtual models in order to document and better understand features of various kinds of data collected during excavations of the Polish Archaeological Mission of the University of Warsaw at Kato Paphos in Cyprus. During several recent seasons of excavations we tested a few methods of generating 3D spatial data, among others the image-based modelling and the structured light 3D scanner. As an interdisciplinary group of architects and archaeologists we used them for different kinds of objects: from relatively small pieces of architectural details and sculpture (e.g. fragments of columns, cornices, altars, etc.), through archaeological trenches to fragments of bigger structures and edifices. Most of the objects, independently of their size and scale, belonged to architectural remains. The comparison of methods and workflows with spatial data on the field helped us to find the best solution for multidisciplinary studies on the archaeological site of the Greek and Roman residential settlement in Kato Paphos.

Keywords: image-based modelling, archaeological decoration, Cypriot capitals, computer anastylosis

Introduction

This paper discusses how visualisation is used as a tool for studying architecture. Creating a virtual reality model of buildings has a very long tradition, especially when we consider traditional methods such as axonometric or perspective drawings showing hypothetical reconstructions of places, cities, dwellings or buildings that no longer exist. This kind of tool usage is one of the oldest and most basic applications of visualisation.

However, the use of 3D modelling as a recording and reconstruction technique has exploded in the last few years, so much that it has almost become a basic tool for modern archaeological projects. In this paper we present the way we use 3D models to document fragments of preserved architectural decoration in combination with long-used, traditional methods. We focus specifically on how visualisation might be used not only to generate views and models of non-existent architecture but to analyse preserved fragments of architectural details.

Archaeological and Historical Context

The examples of the architectural decoration we discuss come from the ancient city of Nea Paphos on the south-west coast of Cyprus. The city developed mostly during the Hellenistic and Roman periods and became the capital of the island. Most of the blocks were discovered in the southern part of the city where its residential quarter was located. There are relics of several extensive edifices dated from the Late Classic period till the Late Roman period (4 century BC – 5 century AD). The city was destroyed many times by earthquakes, and the present state of the architectural structures is a result of natural catastrophes as well as the activity of the squatters in very late antiquity. The remnants of the architecture take a form of the lower parts of the walls preserved up to the height of approximately 0.5 m and rubble filling the interior of the rooms, courtyards and streets. The rubble consisted among others of many fragments of architectural details.

Methodology

Most pieces of architectural decoration have no direct connection with particular buildings and are heavily destroyed[1]. The selected, most valuable fragments have been documented since 1970, primarily using the traditional methods and recently with diverse methods of obtaining the 3D models. The traditional way of documenting the architectural decoration was based on drawings. The greatest disadvantage of this method is the necessity of simplifying the drawings, which means that while preparing them one must reduce the view of the object and basically the drawings become an interpretation not a complete documentation. It certainly has its benefits, like presenting the merits of the objects, but at the same time it is possible to overlook some of their important but not obvious and less visible geometric features.

Primarily the 3D modelling is used to improve and contribute to a process of ongoing archaeological investigation and a post-excavation analysis. Recently it has also become a very important method of visualizing cultural heritage: original objects are replaced in Virtual Reality by interactive 3D models, which makes them more accessible and prevent an original structure from being damaged during the analysis process. That is why we started to document the most important architectural details with digital techniques for visualisation and reconstruction.

We used two methods to create the 3D documentation – a handheld 3D laser scanner and close-range photogrammetry. For the purpose of virtual reconstructions, mesh models with a texture were combined and fixed basing on their geometry in external software. The first method was based on the Artec Eva 3D scanner and the supporting software. We had some problems with the usage of the equipment especially in the full sun – the device could not work in sharp light with deep contrasts, a disadvantage pointed out by many scholars (among others Davis et al. 2017). That is why most of the blocks lying in an open area that could not be transported into a roofed or shady space could not be documented with this tool. The second disadvantage was the lack of compatibility of the software with other programs we use to create documentation of the material, another feature often mentioned by other researchers (Gonizzi Barsanti, Remondino, & Visintini 2013: 147; Manferdini et al. 2008: 221). The obvious inconveniences of the scanning method were also the necessity to carry extra equipment – the scanner – and the cost of the device. Both flaws have been widely documented in the research community (e.g., Davis et al. 2017; Gonizzi Barsanti, Remondino, & Visintini 2013, Manferdini et al. 2008).

The drawbacks of the hand-held 3D scanner were particularly striking in comparison with the close-range photogrammetry. For this we used a standard DSLR camera (Canon EOS 6D with 24-100 mm lens) that was also used for regular photo documentation. The image–based modelling is a commonly used method to acquire 3D measurements from multiple views (Remondino and El-Hakim 2006). In this type of modelling we can distinguish close-range photogrammetry as a ground-based technique used to obtain the 3D coordinates of an object from multiple photographs (Matthews 2008: 11-12). For this purpose, we used Agisoft PhotoScan.

3D spatial data are generated from a photogrammetric processing of digital images taken from offset positions, which allow an overlap of around 80% per pair of photographs. The processing steps of matching across the photos in the first stage is based on detecting overlapping points. Points that do not have a disturbed viewpoint or lighting variations allows the software to generate an identification for each point that is relayed onto its local neighbourhood. In the next step, these identifications are used to detect connections between the photos to align them. To deal with the intrinsic and extrinsic orientation parameters of the camera grid algorithms are used to estimate the camera position and then improve

1 More than 800 pieces of architectural decoration have been discovered only on the area under the supervision of the Polish Archaeological Mission. It is very difficult to estimate even approximately the number of such fragments in the whole ancient city of Nea Paphos.

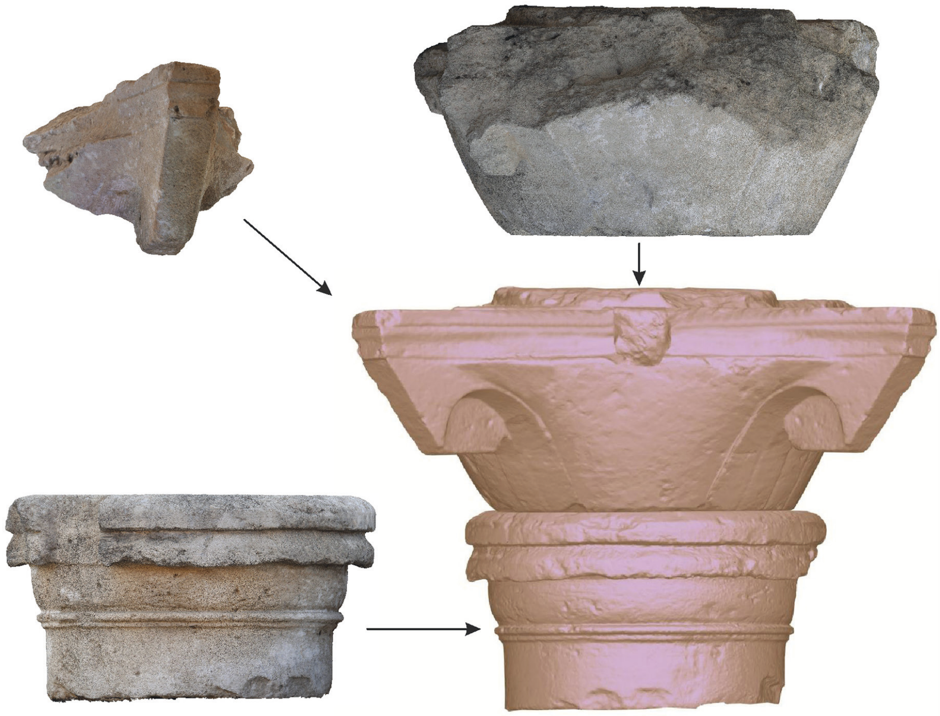

Figure 1. The blocked-out capital from the House of Dionysus – a virtual anastylosis (by A. Kubicka).

the results using a bundle-adjustment algorithm[2]. In the next phase of the workflow, the dense surface is reconstructed where a few algorithms are available. Precisely, height-field methods are used for pairwise depth map computation, whereas an arbitrary method is based on a multi-view approach. At the last stage of workflow texture mapping is carried out where a surface is parameterized by cutting it into smaller pieces. After that source photos are blended to form a texture atlas[3].

Required conditions for the use of the close-range photogrammetry are not as strict as far as distance and light are concerned as compared with a handheld scanner. Some of the pictures of architectural details were taken in the open space because the items were impossible to transfer. It did not influence the precision of the mesh model, however the texture in some cases had to be corrected. The ease of mobility of the close-range photogrammetry allowed us to document several examples of a very specific type of architectural detail: the so-called blocked-out capitals (Figure 1). These details are found in different, distant from one another, archaeological sites of Cyprus. Therefore, you can compare them from different sites with the 3D models.

The reconstruction of the registered element shape was the second part of the 3D documentation workflow. It is based on the combination of two software programs: Agisoft PhotoScan and Z-brush. The synergy of these programs gave us far better results in terms of mesh and texture results for the reconstructed architectural details.

Agisoft was used to create a detailed geometrical model and its texture which then were edited and reconstructed in Z-brush. This workflow is very useful for editing small objects like architectural details. The diversity of tools for sculpturing allows geometrical precision of architectural decoration as well as the reconstruction of the original texture of the stone surface. The combination of the two programs provides the opportunity to obtain a very detailed geometry of the architectural decoration in Agisoft PhotoScan and to project some crucial features of the objects' form in the mesh reconstruction in Z-brush. These two software packages are compatible in terms of the type of exported and imported files. We can export files from Agisoft as .obj with a texture file and then

2 Bundle adjustment is usually used as the final step of every feature-based 3D reconstruction algorithm. It amounts to an optimization problem on the 3D structure and viewing parameters.

3 Technical information based on a description of Dmitry Semyonov on May 03, 2011, AgiSoft LLC, source: http://www.agisoft.com/forum/index.php?topic=89.0.

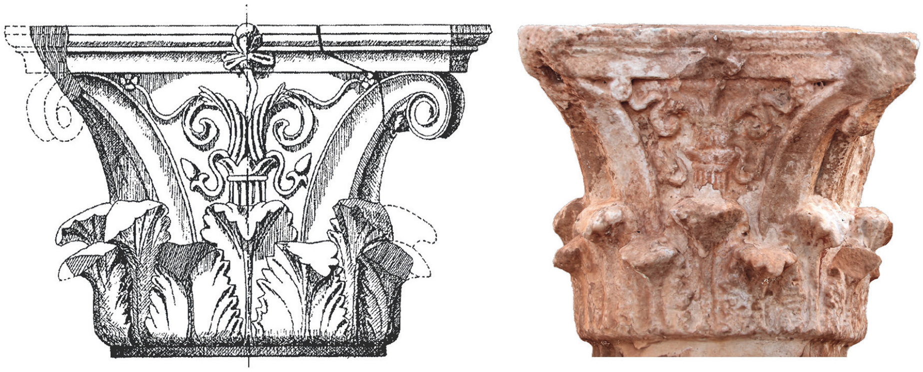

Figure 2. The Corinthian capital from the so-called 'Hellenistic' House: the traditional drawing (by S. Medeksza, 1989) and the 3D model (by A. Kubicka, 2012).

import it to the Z-brush. After some changes or the reconstruction of a mesh model or its optimization, the model can be easily imported back as a mesh to the original Agisoft file and the texture may be created once again, and then if it is necessary edited again in Z-brush. Missing data caused by inaccessible parts of architectural objects create holes in Agisoft mesh models. They can be interpolated automatically in the software. A more geometrically accurate effect can be obtained by sculpturing missing parts in Z-brush. Agisoft allows us also to create 3D pdf files, which are easily accessible and do not require any specialized software to view.

Results

The received 3D models enabled us to conduct very detailed analyses of the pieces regardless of place and time. The differences between the traditional drawing created by using traditional methods from the late 1980's and the orthographic view obtained from the 3D model can be observed by comparing the almost complete Corinthian capital from the main courtyard of the 'Hellenistic' House. The precision of the second method of the documentation is incomparably greater than the first one. It is especially important with fragments characterised by very complex, ornamental decoration, like the capital[4] in Figure 2. In the case of the Corinthian order, the delicate floral decoration of the capital is particularly important as it allows us to establish the estimated time or area of its creation on the basis of its similarity to a certain group of such capitals when its connection with a particular building or structure is uncertain or impossible to establish. This particular Corinthian capital shows a clear relationship with the Alexandrian Corinthian capitals type I and II, which is very important information that helps us date the structure to which the element belonged[5]. As mentioned above, many architectural details from Nea Paphos lack a reliable archaeological context, so the ability to estimate the time of their creation is extremely significant, even with a considerable margin of error due to the judgment conducted only on the basis of formal qualities.

Visualisation of architectural details also allows us to analyse forms that are more complex or more difficult to document, especially with the usage of a traditional, flat drawing. For example, the so called blocked-out capitals, or Nabatean capitals, belong to the characteristic type of the architectural decoration from Nea Paphos. The one presented here was discovered in the House of Dionysus (Figure 3). This kind of very specific capital is widely known from Petra in Jordan, but it also appears in Egypt and Cyprus. At a first glance the element seems very simple, almost devoid of decoration. But this is just a first impression that is misleading, as the capital is characterised by complex although delicate curvatures of the side surfaces.

It is very difficult or almost impossible to present its complete form using traditional methods – the superficial simplicity of the shape and the lack of ornamental decoration leads to very simple vector drawings, which do not reflect the real complexity of

4 Besides obvious differences resulting from the various methods of documenting, there are dissimilarities due to the time passage and exposure to the external conditions, e.g., the lack of one of the corners.

5 It is an example of the so-called Alexandrian decoration known first of all from Ptolemaic and Roman Egypt, but also appearing in Cyprus, which proves strong relations between the Island and Egypt.

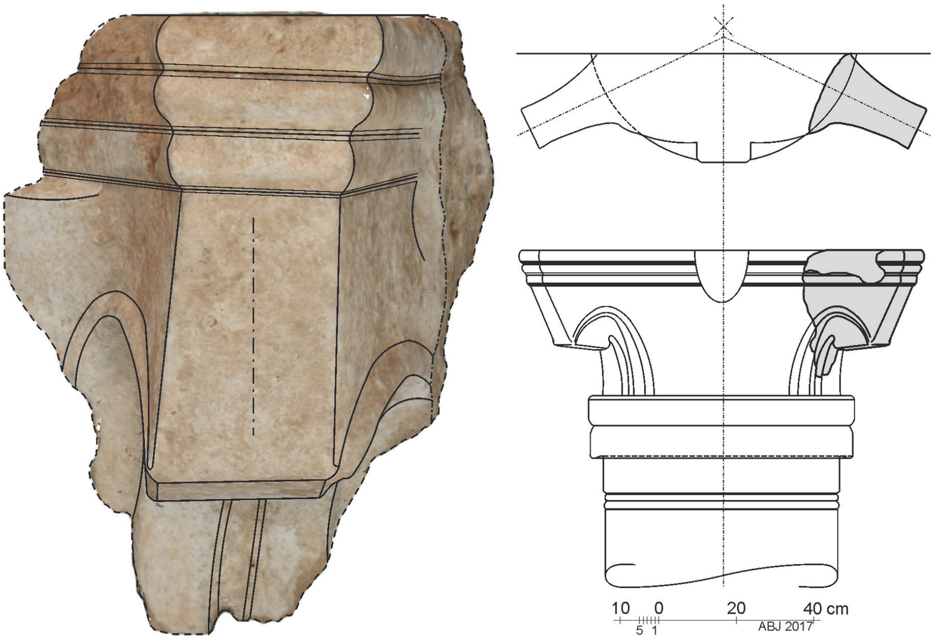

Figure 3. The twisted corner of the blocked-out capital from the so-called 'Hellenistic' House (3D model by A. Kubicka) and the hypothetical reconstruction of the whole capital of the engaged column (by A. Brzozowska-Jawornicka).

the form. The image-based reconstruction allows us to observe and study the spatial aspects of the capital very carefully as well as to document all the damaged and deteriorated parts[6].

On Cyprus this type of the capital frequently appeared as a part of the engaged columns or pilasters. Such types of supports influenced the shape of their capitals – they usually took the form of only a half of its standard form with just two corners (instead of four in a classic capital). These corners were also slightly different from the original version – they were twisted towards each other (see Figure 1). The majority of the preserved Cypriot blocked-out capitals are heavily destroyed, many were found in fragments – usually only the corners survived. In such cases the twist of the corners can be easily overlooked and is very difficult to be documented by a traditional method. The evident advantage of the 3D model is the ability to look at the object from different angles, which increases the possibility of noticing even small details.

Missing some of these important but subtle features may in turn lead to an incorrect reconstruction of the whole capital, and consequently the wrong support (e.g., a free-standing column instead of an engaged column or a pilaster) and moreover a mistaken structure (a portico instead of a pseudoportico). A false interpretation of a relatively small piece of the architectural decoration might cause a completely inaccurate reconstruction of the important part of the building.

The visualisation allows us to examine such a piece very carefully regardless of time and place. The possibility to study the object without the pressure of time (constantly present during excavation seasons) reduces the probability of omission of some important features and consequent misinterpretation errors. What is even more important is the compilation of visualisations of several pieces that allows us to compare them (Figure 4). These comparisons are crucial when there are different variants of the same type of object at some distance from one other and their comparison in situ is impossible.

In addition, the combination of the potentially matching fragments enables us also to create reconstructions – the presented blocked-out capital consists of three pieces lying in distant places but originally belonging to one element– difficult to gather in one place and impossible to check whether they physically fit together. The computer comparison of the 3D elements allows us also to conduct a virtual anastylosis before the physical one or instead of it, if the real one is not possible to execute (Figure 3). This method may also serve as a way to create even more complex reconstructions of preserved fragments.

6 3d modelling and semantic classification of archaeological finds for management and visualization in 3d archaeological databases, p.2-3.

Figure 4. The comparison of the visualisations of fragments of the blocked-out capitals from Nea Paphos (by A. Brzozowska-Jawornicka and A. Kubicka).

Conclusions

3D modelling and reconstruction based on photographs as a methodology of archaeological and architectural research significantly improved the fieldwork and the post-processing of the collected data. The documentation especially may be prepared much faster in terms of the collection of measurements and geometry of the analysed objects. However, the 3D modelling should not exclude traditional methods of documentation based on orientated and scaled 3D models (Kimball 2016): creation of the orthogonal sections and views from the 3D model still ought to be verified on the site in order to exclude misinterpretations of the finds' features. We would also like to emphasize the necessity of the verification of hypotheses in the site – nowadays the 3D models can be observed either on a flat computer screen or as a 3D print. In case of architecture reconstruction, the later usually takes the form of a model in a smaller scale and hence is less precise. Both cases may lead to some mistakes in interpretation. On one hand, the implementation of this technology in most archaeological projects has helped to optimise a time-consuming process of measuring techniques but has not replaced archaeological and architectural interpretation which are still done in the traditional way but with 3D models as a base. On the other hand, the documentation based on post-processing of the 3D models allows us, in many cases, to notice more features of the analysed objects then while preparing the traditional drawing during fieldwork. We can alter the light and shadow parameter or hill-shading techniques changing the reflectance of the surface in virtual reality, which may highlight some of the analysed object's features invisible in situ.

There is also one more advantage of the 3D models worth highlighting as opposed to the traditional documentation: the later method is characterised by the tendency to simplify the drawing and to prepare it in field in a certain scale which inevitably leads to the reduction of the complexity of the documented object. There are no such imposed conditions in working with the 3D models which could be prepared in their actual size and orientation. The only limitation is the size of your computer monitor.

The wide usage of 3D models of architecture as an analysis tool is commonly known (especially ISPRS Journal of Photogrammetry and Remote Sensing e.g.: Faka et al. 2017; Alby et al. 2017). It may be applied to many diverse types of analyses; therefore, the choice of suitable method of 3D modelling is an essential element to achieve sufficient results, meet the goals of the project, which will correspond to an expected degree of measurement accuracy and enable further research on an object or a structure.

Moreover, it is crucial to take into consideration the site's environmental conditions and weather to implement an appropriate method. The choice of the method to obtain a 3D model depends on many factors, the most important from our point of view are mentioned above. In our situation, the close-range photogrammetry seems to be the best solution, especially for the recording of architectural details. However, we plan in the future to expand the project and to create a 3D model of the whole site as complete as possible using a 3D scanner – a better tool for that task. So, as many scholars have pointed out, it seems that a combination of diverse methods may be the best solution (Balletti et al. 2015: 215, 221; Gonizzi Barsanti, Remondino &Visintini (2013): 150; Manferdini et al. 2008: 222).

One more important issue is also worth mentioning here: namely some archaeological projects run for many years or decades. For example, our Mission has been working for more than fifty years at the site. It takes a lot of time to enter all the previously discovered data to the new database, regardless of the chosen method. In such a case constant cooperation between the old documentation and the new one is unavoidable and sometimes it may also cause some problems.

Some other advantages of the 3D models used in archaeology are worth emphasizing. The complex heritage policy of the Department of Antiquities in Cyprus assumes enriching the traditional institutions connected with the preservation of monuments such as Archaeological Parks and Museums with Virtual Reality. Our models may serve in the future as a starting point for a virtual platform for both visitors and scholars enabling to observe, analyse and interact with some objects irrespective of time and place. Such an application of the modelling was also mentioned in the subject literature of Balletti (2015): 218.

Another interesting and very promising idea is a repository or an archive of 3D models of the architectural elements (e.g. columns, capitals, architraves etc) which could help scholars more quickly and more accurately identify a single new object (Manferdini et al. 2008: 221-222; Torres-Martínez et al. 2015: 43). Of course, this method has its obvious limitations such as a wide variety of variants of the analysed elements, but it may, if reasonably used, facilitate the work of an experienced scholar, although it is a topic for discussion in another article.

It seems that analysing architectural decoration by means of 3D models is a technique that is becoming increasingly widespread due to its utility and the advancements of the software and computing power. It may bring new information to researchers that will be helpful to grasp the whole structure to which the decoration originally belonged. The ability to work with the material outside the excavation area and after the excavation season is an obvious but very important advantage of digital modelling. The usage of 3D models as a method of documentation of architectural details allows us to return to the examined object whenever and wherever we want to or need and to understand it better.

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