An Experiment of Integrated Technologies in Digital Archaeology: Creation of New Pipelines to Increase the Perception of Archaeological Data.

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Abstract Digital visualization has gone through a revolutionary decade. Compared to other fields where these methods have been applied, archaeology has been, and still is, more resistant to integrating tools and instruments able to describe materials and scenarios with high resolution. This is partly due to the archaeological misconception of high cost of scientific equipment and the complexity in managing an entire pipeline of data processing. 3D data can be used to describe a huge quantity of information in a single model, and with that, can radically change the traditional way of investigating and interpreting an archaeological context. In this work we explore the potential of using 3D documentation to interpret an archaeological context. Moreover, we try to investigate how a 3D digital methodology can be completely integrated and managed with reasonable costs by archaeologists during an excavation. Furthermore, we test visualization tools such as a cave (an immersive, with the specific purpose to understand how the comprehension and sensory impact of an archaeological context changes in relation to how the 3D data is visualized.

Keywords: integrated technologies, digital methodologies, virtual reality.

1 Introduction

Today the limits in constructing digital methodologies to document and interpret the archaeological excavation cannot be considered just a technological issue. Thanks to the great progress of the last few years in creating tools for the generation and visualization of 3D data, it is now possible to describe all kinds of environments and objects in three dimensions with very good accuracy, affordable prices and without any specific competence in programming.

Up to now, most of the 3D applications in archaeology have been connected with monitoring activities, museums tourism or interaction without risk of damage. However, very little progress has been made on how to use these instruments and methods to create data for the interpretation of the archaeological context.

The goal of defining a standard method for the creation of 3D data in archaeology is still far and probably a bit utopian. Maybe the best approach to apply - in order to start importing these new methods into the investigation process - is a robust research program based on defining easy combinations of tools and instruments to produce a more advanced data documentation.

In this article we describe experiments of digital methodologies in archaeology for the creation of spatial information that fit with the process, the evolution and the investigation of an ongoing archaeological excavation.
It is easy to understand the benefits of a new approach to generate 3D data faster and with higher accuracy, but it is hard to comprehend why these new methods still find so many obstacles in being included into the archaeological activities.

Differently from other contexts, the archaeological excavation and the following investigation process cannot be foreseen. This means that new pipelines and solutions have to be reconsidered every time, according to the resources available. The archaeological working field is dynamic and its evolution is defined by the delicate relation between the field investigation and the documentation process. The result of this activity is an interpretation of the archaeological context based on the analysis of all the elements collected during the investigation.

This process, even if based on scientific information, is very heterogeneous since it is centered on the own capacity of every archaeologist and his/her team to elaborate and analyze data of different nature.
In order to increase the interpretative aspect of the archaeological site, it is important to focus on the elements that generally augment the human capacity to elaborate information.
In archaeology, these elements can be easily recognized in the possibility to see - multiple times and in the same environment - already destroyed archaeological layers or in visualizing specific elements, such as artifacts or bones, in their original position and in relation with the excavation (Figure 1). All these operations have been part of the archaeological process since the beginning of this discipline. With the introduction of new technologies and more powerful visualization tools, it is today possible to exponentially increase the data used by the archaeologist to interpret the archaeological contexts.

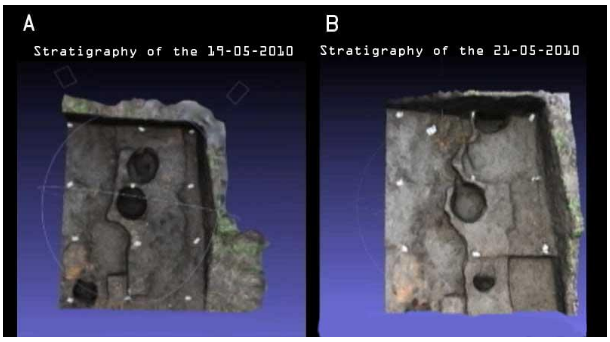

Figure 1: *This image shows two different layers of the same archaeological area in Uppåkra, Sweden. These two models -realized in few hours using this methodology - provide an example of how easy it can be to realize 3D models to monitoring, comparing and analyzing documentation during an excavation campaign.*

In the first part of this article we will describe an experiment of 3D data construction tested on different archaeological case studies in Scandinavia. In specific, we used techniques of image-based 3D modeling for the data capturing and open source software to post process and analyze the models.
The aim of these experiments was to test this methodology in archaeological case studies which presented completely different characteristics, in order to understand the efficiency and the potentialities of this pipeline.
The second part is focused on a visualization experiment realized to investigate the potentialities of immersive visualization systems used to explore archaeological contexts recorded with the technique previously described.

2 Methodology

In the last few years, 3D scanning and other acquisition techniques have been extensively employed in archaeology. Nevertheless, 3D scanning is still not perfectly integrated in the context of an archaeological excavation. This is due to several reasons: among them, the cost of the hardware, the need of expertise to use it and the difficulty to handle large data sets.
However, in the last few years, the efficiency of the structure-from-motion and dense stereo matching techniques has led to the creation of extremely robust and almost automatic methods to reconstruct a 3D model from a set of uncalibrated images. For each couple of images, a number of corresponding features is found, and this leads to an estimation of the camera parameters associated to each photo of the set. The final result is essentially a depth map for each image, where a 3D coordinate is associated to each pixel. Moreover, it is possible to assign a quality value for each point, based on the number of times it occurs among the images.

Although this is not a measurement process, like 3D scanning, the geometry that is produced can be perfectly suitable for the interpretation of a site, which is one of the main goals for an archaeologist.

Moreover, the acquisition of data and the production of the 3D model are quite easy, and the quality of the results is usually accurate even with the use of off-the-shelf digital cameras.

Essentially, the new 3D reconstruction techniques are smart and parallelized combinations of image processing and stereo matching techniques. In most of the cases, the processing is obtained through a web-service approach, where the user uploads the images of the object of interest.
The web-service can provide the final 3D model, or the depth map associated to each image of the set. In the first case, there is usually little further processing to do on the 3D model. In the second case, the process of creation of the final result can be a bit more complex, but it could provide a lot of possibilities to clean and enhance the 3D model.

Nevertheless, 3D reconstruction from images has the potential to be easily integrated in the everyday work in an excavation site due to the very short time needed for the data acquisition, and the re-usability of these data for the excavation documentation.

In this paper, we present a test case where the final 3D models were obtained with almost no cost in terms of hardware, in a short time and using only freeware tools. The goal is to show that in the future it will be possible to obtain a three-dimensional accurate documentation of an archaeological excavation, using only a simple digital camera.

In particular, we show a test case regarding the visualization of different archaeological excavations of southern Sweden and Denmark. After a brief photographic campaign, it was possible to realize several complete 3D models of different archaeological contexts.

We decided to test this methodology on three cases in order to check the functionality in completely different archaeological situations.

The first test was run on a rune stone located in "Runstenskullen" in Lundagård, the historical center of the city of Lund, Sweden. This monument - part of a group of six - was erected during the year 1868 in occasion of the 200th anniversary of the founding of Lund University. The stones within the monument are roughly dated to the 11th century, i.e. the Viking Age of Scandinavia, and have been moved to Lund from Valleberga in Skåne (South Sweden).

The second test was run in Denmark in the area of the Hornsherred, between the fiord of Roskilde and Isefjord on Zealand. Object of this test was a megalithic tomb, Nissehøj, composed of a funeral chamber of approximately 9x1.5x2.6 meters and of a 5 meter long corridor. The architecture is composed of 13 monoliths that define the perimeter and 5 monoliths for the roof.
These tombs belong to the so called *"Funnel Beaker Culture"* and are dated between 3250 and 3100 B.C.

The last case where we tested this methodology was the archaeological site of Uppåkra.
Uppåkra is an ongoing archaeological excavation in southern Sweden that in the recent years has proven to be southern Sweden's largest, most rich in artifacts and longest inhabited Iron Age settlement.
It was an urban settlement where intensive and complex activities were conducted from about the first century BC to about 1000 AD. Despite only smaller areas of the site having yet been investigated, archaeologists are convinced that Uppåkra served as an economic, political and religious centre of power for a large part of the region. Uppåkra may have been the royal seat of a Skåne kingdom.

2.1 Photographic campaign

As explained in the previously paragraph the photographic campaign is the most delicate part of the whole process; in fact, the quality of 3D models generated by this technique depends entirely from the pictures previously acquired during the documentation campaigns. Differently from other environments - where it is possible to settle specific photographic sets and realize images with perfect light conditions - the archaeological field always presents different environmental situations. Most of the time, finding the proper light settings to realize a good photographic campaign is not a simple task.

In the situation of not being able to influence the environmental light settings – as in the case of the archaeological excavation – it is very important to find the best balance between camera parameters and camera positions path. A good combination of these two operations allows creating, in most cases, the right conditions to realize a very good photographic campaign.

The environmental and light conditions of the three sites presented in this article show completely different characteristics. In order to increase our chances to succeed in realizing good pictures to process, for every photographic campaign we previously planned the camera stations, the best focal lens to apply and the ISO[1] settings to use.

The first photographic campaign was realized to document the rune stone in the city center of Lund, Sweden. For this monument we acquired 25 pictures with a resolution of 3088x2056 pixels and we used a semi-professional camera –Canon EOS 450.
Because the dark conditions of the light during the winter, we set the indication of sensitivity of the image sensor of our camera to 1600. In this way we obtained a more bright set of images to upload to the web service.
Planning the position of the camera stations was very easy. In fact the lack of architectonical and natural obstacles around the monument allowed taking all the pictures walking in a circle around the rune stone. This first photographic campaign took approximately fifteen minutes. (Figure 2a)

[1] In photography, an ISO number is an indication of the sensitivity of the image sensor, where a higher number indicates higher sensitivity. This is usually expressed as a range, e.g. ISO 100 - 1600. A higher sensitivity allows us to take pictures in low light without using flash.

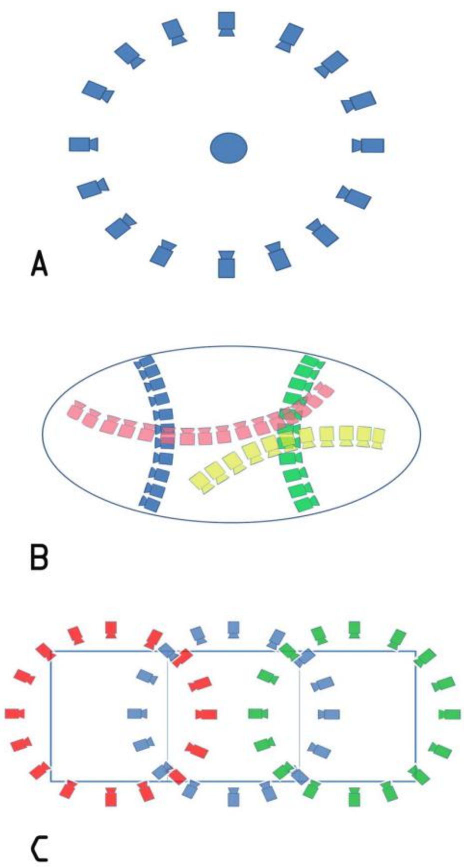

Figure 2: *This image shows a schematic view of the different photographic approaches adopted for the three case studies described in this paper. The first image (a) shows a top view of the camera positions adopted during the photographic campaign of the rune-stone in Lund. The second image (b) shows a top view of the camera positions adopted during the photographic campaign inside the Megalithic Tomb in Denmark. The third image (c) shows a top view of the camera positions adopted during the photographic campaign of the archaeological site of Uppåkra.*

The second photographic campaign was realized in Denmark. Object of this image acquisition was the Megalithic Tomb of Nissehøj. This incredible monument presented very extreme characteristics such as absence of light inside the funeral chamber and a very narrow space for moving the camera.

At the beginning of the mission we were very skeptical about the opportunity to get any result from this second experiment, especially due to the incapacity of our camera to support such powerful wide angles lens. For this reason we decided to use a different camera, an Olympus E-420 that allows supporting a powerful wide angle lens.

Differently from the first case study, using this technique it was impossible to realize a model of the chamber just by interpolating one set of pictures. The single possible solution for us to succeed was realizing multiple set of images of different part of the chamber, with the purpose to get several 3D models to merge together in a second step of the process (Figure 3).

To solve the problem of the light we used two diffuse light spots of 45x65cm each one in order to recreate the best light conditions inside the chamber.

For this second photographic campaign we realized 14 sets of images for a total of 150 pictures with a resolution of 2560x1920 pixels. In this specific situation, for all the images acquired we set the indication of sensitivity to 400. This photographic campaign took approximately four hours.

The third photographic campaign was realized to document a specific area of the ongoing excavation of Uppåkra, Sweden. The goal of this test was the acquisition of a surface of approximately fifteen square meters of the archaeological excavation area. The excavation is covered by a tent that allows the archaeologists to work in all the weather conditions.

After a brief analysis of the field, we decided to split the area in three different acquisitions. The use of this strategy allowed finding a good balance between models resolution and the number of 3D elements to merge together in a second step (Figure 2c). Moreover the possibility to recognize directly in the pictures a metric grid used by the archaeologist inside the excavation allowed easy scaling and orientation of the models realized during the photographic campaign.

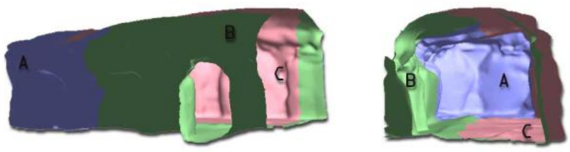

Figure 3: *This image shows a screen shot of the 3D model of the Megalithic Tomb of Nissehøj during the elaboration process in Meshlab. The final model is composed by the merging of several smaller models (a,b,c) previously realized with this methodology.*

Despite the presence of the tent and the possibility inside this structure to use electricity, we decided to not use diffuse lights. In fact this structure permitted a homogeneous distribution of the daylight all over the excavation surface creating a perfect natural light set. For this case study we realized three sets of images for a total of 100 pictures with a resolution of 3088x2056 pixels. We used a Canon EOS 450 and we set the indication of sensitivity to 800.

2.2 Post processing and comparison between the different case studies

The reconstruction of the geometry starting from the acquired image sets was performed using Arc3D, a free web-service which is integrated, for the post-processing step, with MeshLab, an open source tool for mesh processing.

Using MeshLab, it is possible to read the output of the Arc3D service, and define a work pipeline to obtain a "clean" and accurate final 3D model.

The main steps of the pipeline are:

- The generation of the initial 3D model starting from the images. The Meshlab plugin shows in an intuitive way the quality associated to the images of the photo set, so that it is possible to build the geometry by using only a subset of them. Moreover, features like hole filling and image masking give the possibility to iteratively perform the reconstruct to enhance results.
- The remeshing of the obtained 3D model: this operation usually removes some of the noise in the initial surface, and closes coherently most of the small holes. After the remeshing phase (i.e. Poisson) usually some simple cleaning operations are needed.
- Since the color information is lost during the remeshing phase, a simple color attribute transfer filter permits to preserve the color.
- Finally, the model needs to be scaled by taking into account the physical measure of an easy to find geometric feature on the model.

Following this simple pipeline, it was possible to obtain a satisfying model for each of the previously presented test cases.

A further enhancing operation can be applied by using some state-of-the-art approaches for color projection from images. In this way, it is possible to improve the color detail.
Using an automatic approach (CORSINI et al. 2009) to align images on the 3D model, the camera parameters associated to the images used for reconstruction are estimated again in order to improve the registration quality.
Then, after finding a parameterization of the 3D model using MeshLab or any other 3D editing tool like Blender, another automatic method (CALLIERI et al, 2008) fills the texture of the model by improving the detail of color information.
Also this simple pipeline can be completed in a short time, with an extremely low manual intervention by the user.
Finally, MeshLab offers a wide range of possibility for the analysis and presentation of the 3D model.

For all the three case studies the same post processing pipeline as previously described was applied, except for some additional passage required for the realization of the Megalithic Tomb of Nissehøj. Once we had obtained all the single models, in order to build a complete model of the funeral chamber, we used the Align tool of MeshLab to glue all the meshes together, obtaining a unique model of the site.
Comparing with the other case studies, this model presented higher distortion of the mesh; this result was due to the use of a very strong wide angle during the photographic campaign and to the impossibility inside the chamber to take pictures from many different angles (Figure 2a).
An interesting combination of tools that we tested in MeshLab in this experiment is the *vertex attributes transfer* with the *trivial pre triangle parameterization* tools. If used properly, the combination is very powerful because it allows a very quick and functional projection of the color information directly on the models.
For the archaeological investigation – where part of the process is based on the observation of all the elements which compose the stratigraphy – the use of these tools allow creating a perfect replica of the real information, combining in little time a dense geometry with an high resolution image.

Despite the different and complex geometries obtained after the elaboration of the three case studies presented in this paper, the application of these tools worked perfectly with no exceptions in either one of the three situations presented.
This methodology is extremely simple and there is no need for strong expertise in the field of mesh processing and 3D graphics. Moreover, a few intuitive parameters can be changed in order to improve the result and deal with the different requirements of the applications (Figure 4).

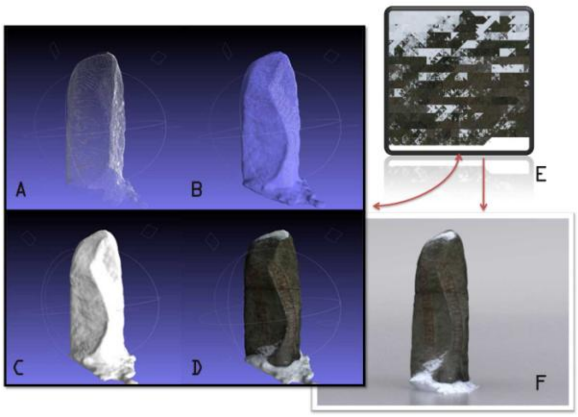

Figure 4: *This image shows the post processing pipeline realized in Meshlab to elaborate the Rune Stone test case.* ***Point A****: elaboration of the point cloud model from Arc3D.* ***Point B****: application of filters to clean and optimize the model in Meshlab.* ***Point C:*** *mesh model realized using the Poisson Filter in Meshlab.* ***Point D****: texturing process realized projecting on the virtual surface the color information coming from the original 3D model.* ***Point E:*** *color map realized after the parameterization process in Meshlab.* ***Point F****: rendering of the 3D model realized in 3DStudioMax.*

This method permits to draw a cyber map of all the information concerning the archaeological context directly inside a perfect virtual replica of the excavation.

Experiment of visualization using a Cave Automatic Virtual Environments

After the elaboration of the models we decided to visualize part of them inside one of the biggest Cave Automatic Virtual Environments (CAVE) of Northern Europe. A CAVE is an immersive virtual reality system where projectors are directed to the four walls of a cube-sized room. Inside this room, it is possible to simulate any kind of virtual environment in full scale and with a very high realism.

We decided to visualize our data in order to test the real potentialities of the developed 3D models and their capacity to create a multidisciplinary debate about their interpretation and connection with different spatial data.

In order to visualize the 3D models inside the virtual cave, no specific data processing was required. Once generated, we imported the mesh models inside the EON Studio software. Through this product it was possible to manage inside the cave all the 3D models previously realized (Figure 5). The visualization of the archaeological contexts into this system was very impressive. During this part of the experiment we were able to explore in real time layers of archaeological excavations - that do not exist anymore - in full scale and with a very high resolution. Moreover, the possibility to analyze, together with other people, specific aspects of the investigation run in the field increased the discussion about different aspects of the sites. This experiment of visualization helped us to understand how far this kind of data can be used to interpret archaeological contexts of monuments or ongoing excavation. In fact, the possibility to easily elaborate and use 3D information– without any specific post processing – in multiple visualization environments proves the dynamism of data realized with this methodology.

Another interesting aspect of this system is its capacity to provide a multiuser visualization of the data from different perspectives. Actually, it is possible for a group of users to explore together multiple virtual models of the archaeological excavation, switching in real time to different moments of the site investigation process. From this experiment we had a strong feedback on the potential of having a huge amount of 3D data realized to describe and testify the entire investigation process realized during the excavation.

Figure 5: *This image shows the 3D model of the Megalithic Tomb of Nissehøj visualized inside the CAVE of Lund University.*

Conclusions

The experiments described in this paper allowed testing a very functional methodology for the description and the documentation of different archaeological sites categories. The extreme simplicity of this approach and its low costs allows its use inside any archaeological excavation. The possibility to easily import these new methodologies in the field of archaeology will bring researchers to face new methodological questions about how to use and interpolate information coming from new data typologies and how to store and organize efficiently these new libraries.

The 3D models realized to document and study the archaeological context can also be used to more easily explain how the archaeologists elaborate any specific interpretation of the site. If properly used, these models can be employed as a visual language to explain the connection between the site and its interpretation. This operation will enable to communicate - inside museums, exhibitions anduniversities - not only information but a complete investigation process.

References

CALLIERI M., CIGNONI P., CORSINI M., SCOPIGNO R., 2008. Masked photo blending: mapping dense photographic dataset on high-resolution sampled 3d models, *Computers and Graphics*, vol. 32, no. 4, page 464--473.

CIGNONI P., CALLIERI M., CORSINI M., DELLEPIANE M., GANOVELLI F., RANZUGLIA G., 2008. Meshlab: an open-source mesh processing tool, in *Sixth Eurographics Italian Chapter Conference*, pp. 129–136.

CORSINI M., DELLEPIANE M., PONCHIO F, SCOPIGNO R., 2009. Image-to-Geometry Registration: a Mutual Information Method exploiting Illumination-related Geometric Properties, *Computer Graphics Forum*, vol.28(7), pp.1755-1764.

DELL'UNTO N., GALEAZZI F., DI IOIA M., 2006 -Via Flaminia project: relief and post processing data techniques in conference proceedings: *From space to place* Rome, Italy

FORTE M.,2008 Cyber Archaeology: an eco - approach to the virtual reconstruction of the past, in *VSMM 2008, Digital Heritage – Proceedings of the 14th International Conference on Virtual Systems and Multimedia*, Limassol, Cyprus

VERGAWEN M., VAN GOOL L., 2006, Web-Based 3D Reconstruction Service", *Machine Vision Applications*, 17, pp. 411-426, 2006

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