

Combining Terrestrial Laser Scanning and Techniques of Digital Image Processing in “Archaeology of the Architecture” Analysis in the Walls of the Andalusian Site of Vascos (Navalmoralejo, Toledo-Spain)

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Abstract

This paper presents the work of 3D recording and geometric documentation of part of the walls of “Ciudad de Vascos” through specific methodologies of Archaeology of the Architecture, with the objective to obtain ‘quickly’ the individual measures of every element which compose the wall. We carried out a topographical survey with a TLS (LeycaScanStation C10), for the geometric and volumetric reconstruction; in addition we used a GPS to give absolute coordinates to the work. We obtained the 3D textured model and a series of plans or sections, like first results of the project, as well as a series of orthoimages that will support to the archaeological study. Finally, we used techniques of digital image processing, mainly: image enhancement, edge detection and filters, in order to ‘automate’ the process of defining structural elements to obtain the measurements requested.

Keywords:

Terrestrial Laser Scanning, Image Enhancement, Edge Detection, Archaeology of the Architecture, “Ciudad de Vascos”

1. Introduction

The aim of this paper is to present the work which we are developing in 3D recording and geometric documentation of part of the walls of the Archaeological Site of “Ciudad de Vascos” in Toledo – Spain; to achieve one of the objectives of *Archeologia della Architettura* the chronology about the typology of the masonry of the buildings (Francovich and Parenti 1988; Quirós, 2002). To delve into this subject, we were looking for a geometric definition and measurement of all elements which compose the wall, and to arrive at this propose we support the study with a survey with Terrestrial Laser Scanner (TLS) technology with the implementation of this data with techniques

of digital image treatment and edge detection (Like in Lambers et al. 2007/ or Natividad and Calvo 2010).

Basically, we propose the use of orthophotos generated from the processing point cloud obtained with a TLS. In these images, we applied techniques to enhance and improve, looking for to extract the edges and to define every element of the structure. The objective of this process has been to facilitate the extraction of numerical data of all the elements of the walls, its dimensions (length, width, area, etc.). For that reason we suggest the implementation of programs used today by the biological sciences, to counting and measuring cells, thus contributing in the mensiochronology methodology that we try to apply at the study.

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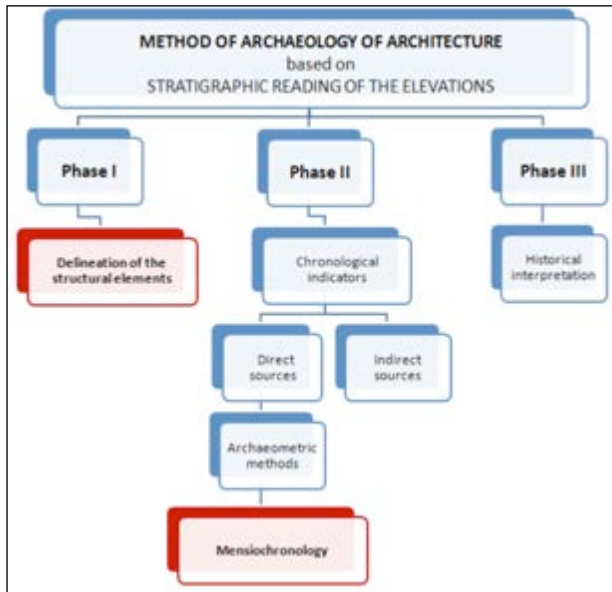


Figure 1. Scheme of the method for Archaeology of Architecture. In red, phases in which the contributions of this methodology are developed.

This brings ‘quickly’ both data, the definition of the geometry and the numerical data to manage with statistical programs. In consequence, these studies, trying to go into the methodology of ‘*Archeologia della Architettura*’, contributing with this idea to arrive at a process of automation of the buildings study.

2. Contributions Between Geomatics Techniques and Archaeology of the Architecture in this Particular Archaeological Site

To study cultural heritage elements using by Archaeology of Architecture method, the stratigraphic readings of the elevations and their type must be analysed. Firstly data are collected, in a critical and analytical way, and secondly the material remains have a stratigraphic study, in order to translate them into suitable documents to be interpreted historically. The stratigraphic reading of the elevations may be organized in three phases (Quirós Castillo 2006):

- I: Definition of archaeological Stratigraphic Units. Drawing and representation of any Stratigraphic Unit and its peculiarities.



Figure 2. View of the Archaeological Remains of “Ciudad de Vascos” www.ciudaddevascos.com.

- II: Absolute dating of stratigraphic sequence, according to structural or temporal arguments into phases and periods of the stratigraphic records.
- III: Finally, the subsequent analysis of the process in the archaeological site is made, that is the historical interpretation of the sequence and the project definition (the typological study).

Without going into great detail, our work is focused specifically on Phase I, which contains the delineation of the structural elements, for which some method of data collection and processing of spatial data is needed, finally we could obtain the 2D and/or 3D representation of the study element; and Phase II, in which measurements of dimensional features of the elements are made as the study base as archaeometric methods, in particular for the mensiochronology technique (Quiros 1996) (Fig. 1).

In this particular archaeological site, we have known through the different excavations, alongside specific analytical tools applied to the wall of the city, that this *madīna* -city- «called Ciudad de Vascos» could have had an occupation between the IX and XI centuries (Izquierdo 2005).

That information is very important because that period was the control of the Umayyad dynasty, from Córdoba, when the important wall of the *madīna* was erected. Hence, the wall-fortress was erected alongside



Figure 3. Study zone and location of the scanner stations (V-i) and targets (T-i) for georeferencing.

some constructive parameters which include common features founded in the Umayyad architecture, either in Middle East or in the Iberian Peninsula. In any case, some differences within the same building allow us to define probable chronological or constructive phases, allowing us to discuss about local variations, which we should find in every dimension of the building.

Our objective is going into the first and second phase of the methodology, to serialize the building functionally and chronologically

through the measurement beyond the data. Therefore, one of the main elements to take into account is the analysis of the variation and similarities of the modules and measures of the edification (i.e. dimensions of ashlar, masonry...).

Specifically this study is located on the west side of the wall, between the first and second towers, and the one of the main entrances to the city, The West Gate, a special point of political propaganda as demonstrated by the horseshoe arch carved into the ashlar. In these areas of the wall we can see a sample of the 'official' construction, which have interpreted like an Umayyad building (Torres 1957; Pavón 1987; 1991; Zozaya 2009).

3. Materials and Methods

The methodology detailed below has been divided both in fieldwork and office work. The necessary fieldworks for the empirical study are composed mainly of archaeology and topographic surveys. The office work has been more diverse and may be mentioned from the literature review, the data processing and coordinates calculation, the digital image processing and the dimensional measurements of ashlar and other structural elements that form the studied section.

3.1 Field Data Collection

We carried out a 3D T.L.S. survey with a Leica Geosystems ScanStation C10, on the west side of the wall of "Vascos". In total, there were 12 T.L.S. locations, taking one point every 2 mm, of which seven (V-1 to V-7) are outside the wall, and the rest in the interior (V-8 to V-12). The results of these scans are a point cloud of 13,647,654 points, formed by the coordinates (X, Y, Z), the three colour components (RGB) and the intensity (I) of each record point of the wall (Fig. 3). The planning for this phase is absolutely necessary as the optimal location of the scanner ensures the complete definition

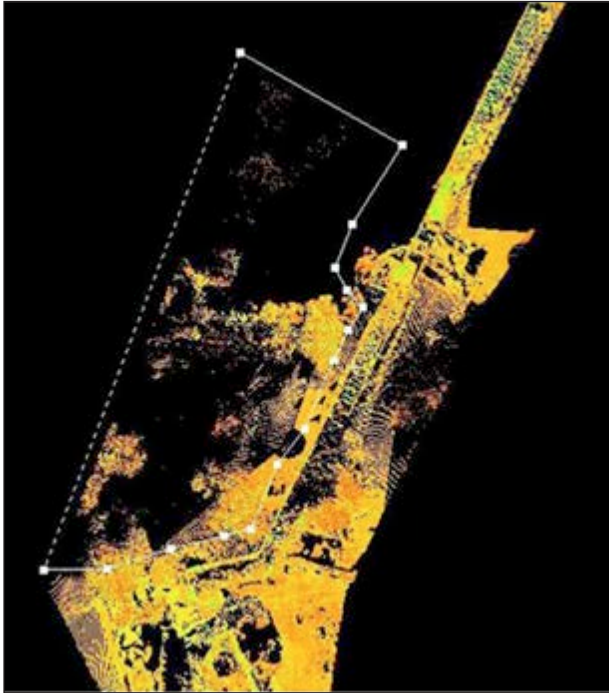


Figure 4. The image shows one of the polygons through which cleaning is performed.

of the element, due to the complex topography and the possibility of occlusions and shadows. Targets were used to georeferencing work, positioned so these may be visible from several scans, to which they were given absolute coordinates using GPS techniques and the RTK method.

3.2 Registration

The office works began processing the data captured in the field with the T.L.S. The first step was the registration of multiple scans that consist of aligns georeference and combines the multiple data sets in order to get a complete 3D cloud. It was used on the module Cyclone Register.

In our case, the registration was done by the software, in an iterative process for which at least two common points in each point cloud are necessary, these are the registered targets. In this case it may be complex because the masonry is not defined by clear edges, but they are rounded, and there are no clearly defined points that can be identified without doubt in the different scans.

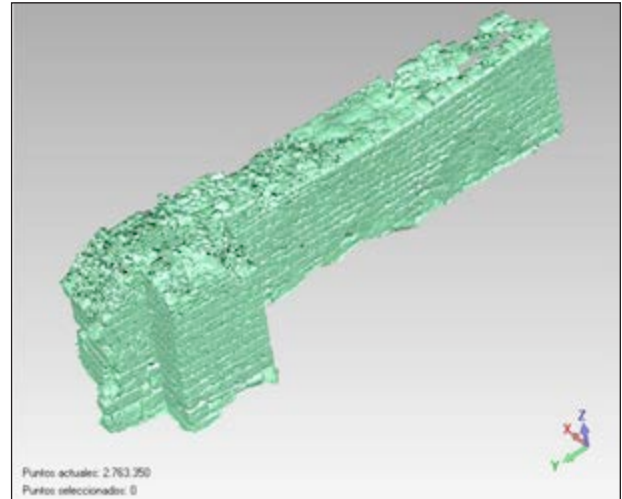


Figure 5. Picture of outside of sub-area 7.1, loaded as .pts file format in Geomagic Studio software.

3.3 Cleaning the Point Cloud

At this stage, we cleaned all the noise of the scans, mainly undergrowth and vegetation, leaving only the wall remains. This information to delete was completely removed without possibility of recovery, and it made completely in manual form (Fig. 4).

3.4 Meshing

Geomagic Studio 12.0 software was used to obtain the triangles mesh. This software has a large computational power, and supports a comprehensive range of 3D scanners in XYZ / ASCII format, like the Leica data in .pts file format, which includes the coordinates, the colour information (RGB) and intensity corresponding of each point. But in this case, it was decided to transform the data format to .pts file format (only coordinates) and let the default appearance that the program gave to the mesh (Fig. 5).

Furthermore, due to the large amount of data captured, a single mesh for the area of study becomes very heavy, it was necessary to divide the area of study into smaller parts thus to determine different zones and subzones.

The main problems at this stage were that all zones had hidden areas by the vegetation

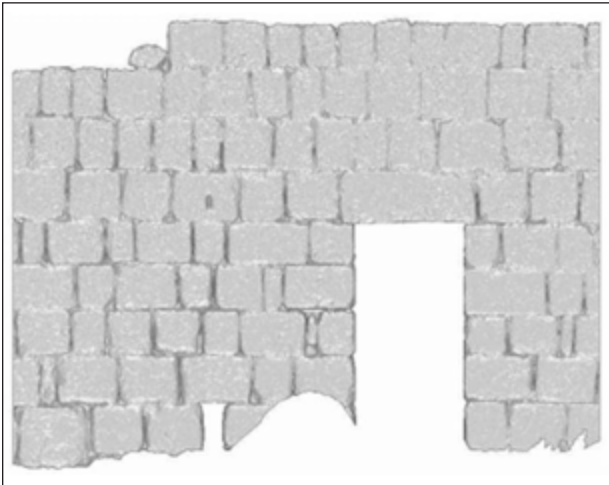


Figure 6. Orthoimage of outside of subarea 4.1.

and undergrowth although the wall has been cleaned before the survey; besides there were trees that we could not cut off for Conservation Nature reasons.

3.5 Orthophotos

With the same software (Geomagic Studio 12.0) textured ortho-images of all elevations were generated. Which was a product derived from the triangle mesh with a resolution of 96 pixels per inch, whose aim was to provide us the basis for future treatments, like the archaeological study of the structural elements (Fig.6).

In this case, we decided not to work with photographs, which came from the textured model, our objective was to subject these ortho-images of different digital image processing.

3.6 Line Drawing of Structural Elements

This process can be accomplished directly from the 3D point cloud, i.e. using the point cloud as base from which geometric features are traced, thus creating a vector model, or delineating manually from orthoimage. But our proposal is to use image treatment and enhancement techniques, to extract the edges of the structural elements and 'automate' the process.

The software that we used in this part of the work was GYMP 2.6., which has the added advantage of being free software.

The main aim was to highlight the edges of each one of the elements that form the walls. They should be treated as a separate object. In an image, which defines that an element is distinguished from another is the difference between Digital Levels (DL) of each one, that is, each image pixel has a lower or higher DL than their neighbours. Thus, an element is defined by a set of pixels adjacent with identical or very similar DL value, and its limits are marked by a change in the DL value. By spatial contrast, i.e. the difference between the digital level of a pixel and the neighbouring pixels, we define each object using filtering techniques, smoothing or enhancing these contrasts, and edge detection.

Firstly, a phase of noise reduction is performed, consisting in removing residual information by the application of the 'Gaussian filter' and a 'Non-linear filter'. Then, edges were delineated by the application of the 'Sobel' and 'Laplacian' filters. The results were not completely satisfactory, since the ashlar and masonry were not entirely demarcated, for that we were looking for an alternative. 'Tampon filter' of Photoshop simplifies the image to appear stamped with a rubber stamp, which shows the pixels continuously, creating closed shapes more or less homogeneous and resulting in the best way to define the ashlar, and other elements of the wall, as individual and closed forms.

3.7 Dimensional Measurement of Structural Elements

The last phase of our work was to calculate the dimensional measurement of each of the structural elements, mainly the ashlar and masonry areas. The Aphelion® Dev software has been developed by the biologists to carry out counting and measuring cells for further studies. In that direction we thought to use this program to determine the width and height of

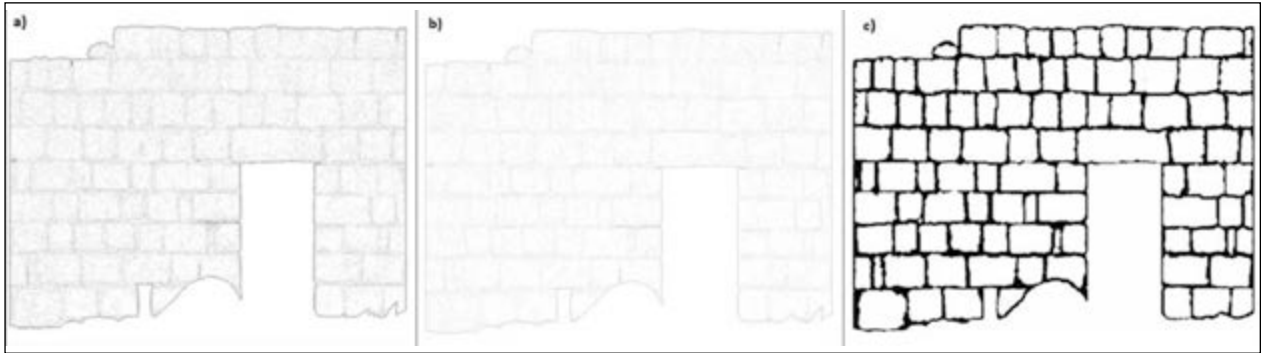


Figure 7. Image of outside of Subzone 4.1 treated with a) 'Sobel filter', b) 'Laplace filter' and c) 'Tampon filter'.

each element. One of the requirements of the program is to work only with binary images, i.e. black and white, so it was necessary to divide the process into three phases: defining a reference standard and setting the measurement units (inches, centimetres, pixels ...), excluding values for unwanted digital levels, since images resulting from treatment with Tampon filter because they are not exactly binaries and finally launching in the program the measure of the elements of study. Thus, it was possible to detect defined surfaces (closed) with the same digital level (Fig. 8).

As the result, a table with the number of ashlar or masonry element and the height and width is obtained, necessary parameters to proceed to the temporal study by mensiochronology.

3.8 Results Verification

Finally, the process of results verification helps to validate the obtained results. Thirty elements for each study zone were randomly chosen, its measurements were taken in site, the height and width of the ashlar and masonry stones that make up each facade, carrying out a statistical analysis that consists of calculating the residuals and the study of the error behaviour for each study zone, to give the quality value of our work.

To set a maximum error to help us in defining the accuracy and precision of the work, we follow the same criteria of any topographical survey, where accuracy is given by the limit of

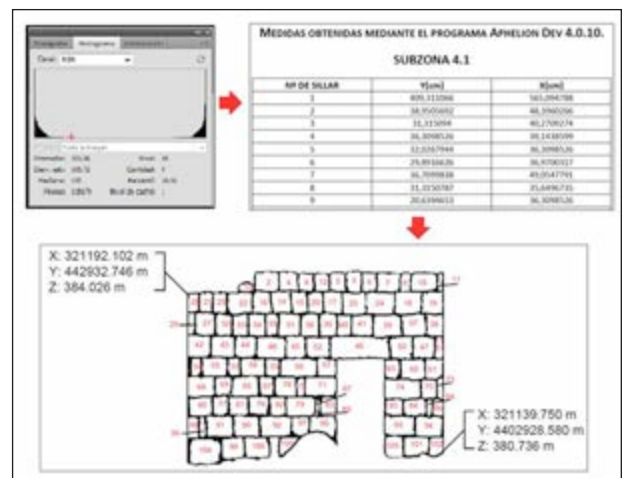


Figure 8. Results of the classification and the dimensional measurements of structural elements in the outside of subarea 4.1.

visual perception ($0.2 \text{ mm} * N$, where N is the denominator of the scale). Whereas we work with a representation of the information to 1:100 scale, this value would be two centimetres. On this basis, we can calculate what percentage of the residuals of each sample is among the values of -2 and +2 centimetres. This criterion was fixed between both parts of the team. The archaeological reason has been taken in 2 centimetres, because it is possible to obtain a medium-range of the 'official' measures, which the andalusies constructors may be used, and the difference could come for the limitation of the construction tools.

On the other hand, to analyze possible systematic error sources, a graphic representation on the study zones was made where, in a visually way, through a colour scale it can be seen how residuals are distributed.

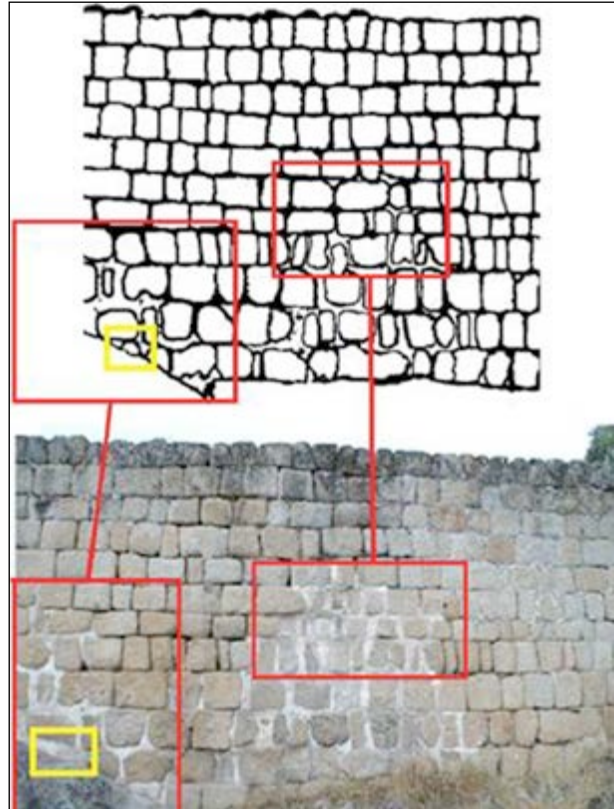
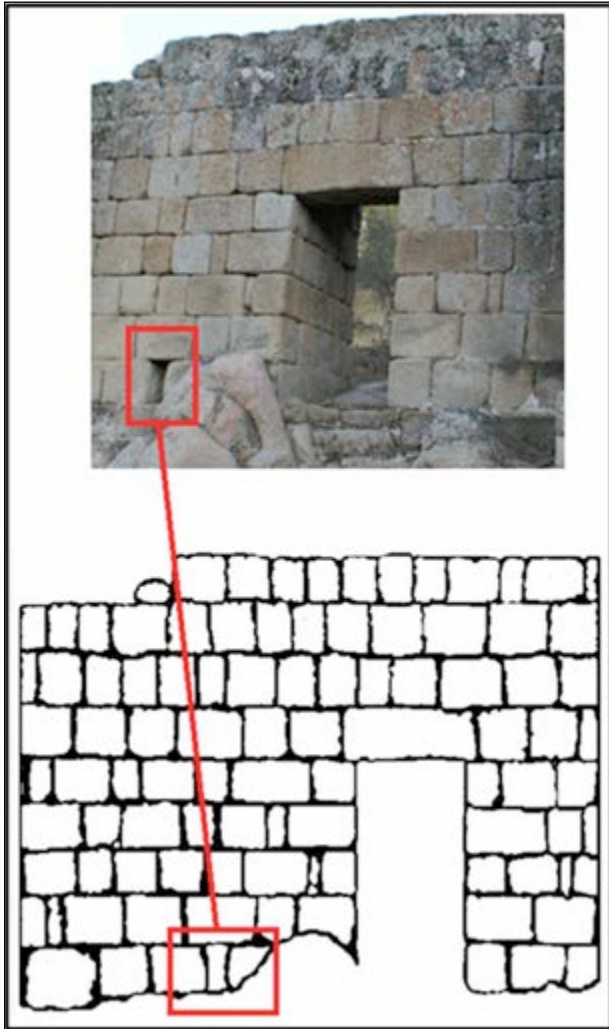


Figure 9. Image of some of the main problems when trying to define different elements with that method. a) Waste pipes which had to be defined manually, b) Errors caused for the joints of lime mortar.

4. Analysis and Results

Even though we have already focused to the information about how the analysis of graphic data has been accomplished, and how the measure of each element was calculated. We would like to present some of the main problems we came across when trying to define different elements with that method. Afterwards, we are presenting a brief abstract of the analysis of tolerant value.

Regarding the delineation of structural elements, the mainly faced problems can be summarized in four points:

- Define problems related with the definition of irregular stone mason edges.
- Errors caused for the joints of lime mortar.

- Other problems have been faced regarding certain singular elements, such as waste pipes, which had to be defined manually.
- Finally, an important aspect to deal with was the hidden areas in the digitations. Those areas had to be completed with photogrammetry or another topographic system.

Regarding the general study of tolerance, as mentioned previously, while taking measures, the team chose to do a sampling in each of the four areas studied. Such sampling consisted of taking a total of thirty measures within the site, to contrast them in the laboratory and see the tolerance of the tool in a scale 1:100. Such tolerance was of 2 centimetres, and two variables could be founded: length and height, both of them will be analysed as follow.



Figure 10. Length remainders distribution in centimetres, Subzone 1.

On the first table, subareas 1 and 4.1 can be detected. In the first one, we can observe that the better results lie in the length of the measures, with a ninety one per cent (91%), while the heights have an index higher than the tolerated one. Studying the probable cause, it is possible to detect that the higher output of tolerance can be founded in the irregular stone masonry. Furthermore, it can be observed in that table the surpluses of the length. In only few cases they exceed the two centimetres. Regarding the measures in 4.1 an average index of output of tolerance was detected without a clear pattern of distribution.

In the second table, the subareas 3 and 7 can be observed and also how the success of the tolerance is higher. On the third subarea the height has most of the residuals fluctuating between 0-2 cm. Two cases lie in 3 cm, which represents the ten percent of the total.

Finally, the subarea seven presents some output of tolerance, probably due to the irregular masonry it can be spotted how the length caused an output of tolerance higher in the data. That can be due to the masonry and the need for improvement in the leak of the images. In this case, we wanted to present a

SUBAREA		PERCENTAGE OF VALUE IN TOLERANCE	DISTRIBUTION OF RESIDUALS	ORIGIN OF RESIDUALS
1	LENGTH	91%	Irregular stone masonry, the highest residuals	The irregular stone masonry affects the delineation with image filters
	HEIGHT	57%	Irregular stone masonry, the highest residuals	The irregular stone masonry affects the delineation with image filters
4.1	LENGTH	56%	Uniform distribution	There is no clear pattern
	HEIGHT	77%	Uniform distribution	There is no clear pattern
3	LENGTH	84%	Higher residuals from the centre to the left	Decreasing cloud of points affects the photo rectification
	HEIGHT	90%	Most residuals fluctuate between 0-2 cm. Two cases lie in 3 cm.	No uniform pattern

Table 1. Subareas 1 and 4.1, wall of madīna Vascos.

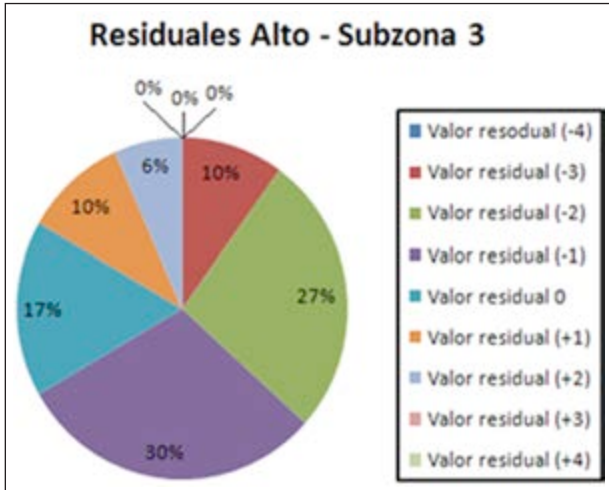


Figure 11. Height remainders- subzone 3.

visual analysis of the percentage in the output of tolerance.

With this study we would like to present some preliminary conclusions, assuming that it is necessary to debug the job related to the post-process of images, even though we can observe that in a scale 1:100 there is an average of 70% of the data (including irregular stone masonry), due to obtain a medium-range.

5. Conclusions

Making a comprehensive assessment of all the work, we could conclude that the data collection by T.L.S. has allowed a greater speed data capture, resulting in significant reduction of time-consuming in the fieldwork and thus, in a reduction of costs, providing an accurate and high detailed three-dimensional record of the walls, impossible to achieve in time and cost by traditional methods (Peripimeno 2005).

One of our main aims was to be able of simplify all processes, although human intervention is required in some specific tasks (i.e. cleaning of some remains of shadows of the point cloud), the phase of the line drawing could be completely automated by the application of edge detection filters and techniques of digital image processing. This graphic record supplemented with the software application for

extraction of the dimensional measures of the elements to be studied, allows us to obtain in a few seconds measurements that, performed by hand, would result in a high temporal cost, depending on sample size.

This methodology developed between archaeologist and topographers, arrives to an important result for the study of the historical buildings, and it has the ability to perform analysis quickly, easily and reliably for a comprehensive historical study of the chronotypology. Future lines of work should further deepen the application of these techniques, which allow the possibility of turning raster information in vector for the subsequent application of the same in, for example, a GIS environment.

By improving this method applied to historic buildings we can achieve the complicated objective of obtaining mensiochronology of any stratigraphic unit and any individual typology. That will enable in the future a quick comparison among buildings chronologically and typologically similar, allowing us to go further in our understanding of the techniques and possible ways to construct in the Middle Ages.

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Contents

Human Computer Interaction, Multimedia, Museums

- 15 Towards Collaborative Decipherment of Non-Verbal Markings in Archaeology**
Barbara Rita Barricelli, Stefano Valtolina, Giovanna Bagnasco Gianni and Alessandra Gobbi
- 21 Archaeological Documentation in the Field: the Case of the Roman Forum of Cástulo**
Ana Martínez Carrillo, Marcelo Castro, Francisco Arias de Haro and Manuel Serrano
- 30 Implications for the Design of Novel Technologies for Archaeological Fieldwork**
Tom Frankland and Graeme Earl
- 37 OpenArchaeoSurvey, or ‘Being Educated by the Digital Fieldwork Assistant’**
Jitte Waagen, Nils de Reus and Rogier Kalkers
- 48 The Use of iPad as a Documenting Tool on an Archaeological Excavation on Govče 2011 Project in North - Eastern Slovenia**
Eva Butina
- 57 Back into Pleistocene Waters. The Narrative Museum of Casal de’ Pazzi (Rome)**
Augusto Palombini, Patrizia Gioia, Antonia Arnoldus-Huyzendveld, Marco Di Ioia and Sofia Pescarin
- 66 Etruscanning 3D: an Innovative Project about Etruscans**
Eva Pietroni, Daniel Pletinckx, Wim Hupperetz and Claudio Rufa
- 77 Personalizing Interactive Digital Storytelling in Archaeological Museums: the CHESS Project**
Laia Pujol-Tost, Maria Roussou, Olivier Balet and Stavroula Poulou
- 91 Installation for Interpretation of Archaeological Sites. The Portus Visualisation Project**
Javier Pereda
- 102 Material Motion: Motion Analysis for Virtual Heritage Reconstruction**
Kirk Woolford and Stuart Dunn
- 110 Interactive Workspace for Exploring Heterogeneous Data**
Uros Damnjanovic and Sorin Hermon

Simulating the Past

- 120 The Use of CFD to Understand Thermal Environments Inside Roman Baths: A Transdisciplinary Approach**
Taylor Oetelaar, Clifton Johnston, David Wood, Lisa Hughes and John Humphrey

- 130 Structural Assessment of Ancient Building Components, the Temple of Artemis at Corfu**
Georg Herdt, Aykut Erkal, Dina D'Ayala and Mark Wilson Jones
- 138 Final Results of the Virtual 3D Reconstruction of the East Pediment of the Temple of Zeus at Olympia**
András Patay-Horváth
- 146 Teaching Cultural Heritage and 3D Modelling through a Virtual Reconstruction of a Medieval Charterhouse**
Andres Bustillo, Ines Miguel, Lena Saladina Iglesias and Ana Maria Peña
- 156 3D Reconstruction in Archaeological Analysis of Medieval Settlements**
Daniele Ferdani and Giovanna Bianchi
- 165 Handling Transparency in 3D Reconstructed Online Environments: Aquae Patavinae VR Case Study**
Daniele Ferdani, Bruno Fanini, Guido Lucci Baldassari, Ivana Cerato, Sofia Pescarin
- 174 3D Documentation for the Assessment of Underwater Archaeological Remains**
Barbara Davidde Petriaggi, Roberto Petriaggi, Gabriele Gomes de Ayala
- 181 Post-Excavation Analysis in Archaeology Using 3D-Technology: the Case Study of Hala Sultan Tekke**
Kostas Anastasiades, Sorin Hermon, Nicola Amico and Giancarlo Iannone, Karin Nys
- 190 A New Approach for Interactive Procedural Modelling in Cultural Heritage**
René Zmugg, Ulrich Krispel, Wolfgang Thaller, Sven Havemann, Martin Pszeida and Dieter W. Fellner
- 205 Virtual Reality Simulations in Cultural Heritage**
Ioanneta Vergi
- 214 Taking Excavation to a Virtual World: Importing Archaeological Spatial Data to Second Life and OpenSim**
Isto Huvila and Kari Uotila
- 221 Using ConML to Visualize the Main Historical Monuments of Crete**
Panagiotis Parthenios
- 225 A High-Performance Computing Simulation of an Irrigation Management System: The Hohokam Water Management Simulation II**
John T. Murphy

Field and Lab Recording

- 232 Application of RTI in Museum Conservation**
Eleni Kotoula
- 241 Automatically Recognizing the Legends of Ancient Roman Republican Coins**
Albert Kavelar, Sebastian Zambanini and Martin Kampel

- 250 Multispectral Imaging of Historic Handwritings**
Fabian Hollaus
- 258 Multispectral Image Analysis of a Censored Postcard from 1942**
Florian Kleber, Fabian Hollaus and Robert Sablatnig
- 264 Semantic Web Technologies Applied to Numismatic Collections**
Ethan Gruber, Sebastian Heath, Andrew Meadows, Daniel Pett, Karsten Tolle and David Wigg-Wolf
- 275 Automatic Coin Classification and Identification**
Reinhold Huber-Mörk
- 289 Archiving Three-Dimensional Archaeology: New Technologies, New Solutions?**
Kieron Niven, Stuart Jeffrey and Julian D. Richards
- 295 Intra-Site Analysis and Photogrammetry: the Case Study of the ‘Buca Di Spaccasasso’ (Grosseto, Italy) an Eneolithic Funerary Site**
Giovanna Pizziolo, Daniele Pirisino, Carlo Tessaro and Nicoletta Volante
- 308 Site Recording Using Automatic Image Based Three Dimensional Reconstruction Techniques**
Victor Ferreira, Luís Mateus and José Aguiar
- 316 Photographic Rectification and Photogrammetric Methodology Applied to the Study of Construction Process of Provincial Forum of Tarraco**
M. Serena Vinci
- 324 Image-Based 3D Documentation of Archaeological Trenches Considering Spatial, Temporal and Semantic Aspects**
Robert Wulff and Reinhard Koch
- 337 Digital Photogrammetry: a Contribution to the Study of Early Middle Ages Sarcophagi Quarries of Panzoult (Indre-et-Loire, France)**
Daniel Morleghem
- 344 Low-Cost Photogrammetry and 3D Scanning: the Documentation of Palaeolithic Parietal Art in El Niño Cave**
Alejandro García Moreno and Diego Garate
- 350 3D Documentation in Archaeology: Recording Las Cuevas Site, Chiquibul Reserve, Belize**
Fabrizio Galeazzi, Holley Moyes and Mark Aldenderfer
- 363 Social Spreading of Geometric, Recorded Data from a Range of Types of 3D Scanners via a Web Data Server**
Jorge Angas and Paula Uribe
- 376 Combining Terrestrial Laser Scanning and Techniques of Digital Image Processing in “Archaeology of the Architecture” Analysis in the Walls of the Andalusian Site of Vascos (Navalmoralejo, Toledo-Spain)**
María J. Iniesto-Alba, Miguel A. Bru Castro, Estela Paradelo Fernández and Pablo Carballo Cruz

- 386 3D Model of the Roman Walls of Lugo (Galicia, Spain) Using a Terrestrial Laser Scanner and an Unmanned Aerial Vehicle**
María J. Iniesto-Alba, Alicia Canizares-Sánchez, David Miranda and Rafael Crecente
- 398 (Re)seeing the Engraved Block of El Mirón Cave (Ramales de la Victoria, Cantabria, Spain)**
Vera Moitinho de Almeida, Luis Teira, Manuel González-Morales, Lawrence G. Straus, Millán Mozota and Ana Blasco
- 406 Meshlab as a Complete Open Tool for the Integration of Photos and Colour with High-Resolution 3D Geometry Data**
Marco Callieri, Guido Ranzuglia, Matteo Dellepiane, Paolo Cignoni and Roberto Scopigno
- 417 Enhancing Surface Features with the Radiance Scaling Meshlab Plugin**
Xavier Granier, Romain Vergne, Romain Pacanowski, Pascal Barla and Patrick Reuter
- 422 OpeninfRA – Storing and Retrieving Information in a Heterogeneous Documentation System**
Alexander Schulze, Frank Henze, Felix F. Schäfer, Philipp Gerth and Frank Schwarzbach
- 432 Towards Reverse Engineering Archaeological Artefacts**
Vera Moitinho de Almeida and Juan Anton Barceló

Data Analysis, Modelling and Sharing

- 444 ARCA: Creating and Integrating Archaeological Databases**
Maria del Carmen Moreno Escobar
- 457 A Database for Radiocarbon Dates. Some Methodological and Theoretical Issues about its Implementation**
Igor Bogdanović, Juan Antonio Barceló and Giacomo Capuzzo
- 468 Standardised Vocabulary in Archaeological Databases**
Matthias Lang, Geoff Carver and Stefan Printz
- 474 Modelling Imperfect Time in Datasets**
Koen Van Daele
- 480 Distribution Analysis of Bone Remains in the Prehistoric Site of Mondeval De Sora (Belluno - Italy): Issues and Proposals**
Maria Chiara Turrini, Federica Fontana, Antonio Guerreschi and Ursula Thun Hohenstein
- 487 Places, People, Events and Stuff; Building Blocks for Archaeological Information Systems**
Paul J. Cripps
- 498 ArcheoInf, the CIDOC-CRM and STELLAR: Workflow, Bottlenecks, and Where do we Go from Here?**
Geoff Carver
- 509 @ OccupyWatlingStreet: Can we find out Who was occupying What, Where and When in the Past?**
Keith May

520 Connecting Archaeology and Architecture in Europeana: the Iberian Digital Collections

Ana Martínez Carrillo, Arturo Ruiz and Alberto Sánchez

527 Open Access Journals in Archaeology and OpenAccessArchaeology.org

Doug Rocks-Macqueen

533 SVG Pottery: Upgrading Pottery Publications to the Web Age

Stefano Costa

541 Through an Urban Archaeological Data Model Handling Data Imperfection

Asma Zoghlami, Cyril de Runz, Dominique Pargny, Eric Desjardin and Herman Akdag

551 Guerrilla Foursquare: a Digital Archaeological Appropriation of Commercial Location-Based Social Networking

Andrew Dufton and Stuart Eve

558 Conceptualising eScience for Archaeology with Digital Infrastructures and Socio-Technical Dynamics

Teija Oikarinen and Helena Karasti

Geospatial Technologies and Analysis

570 Intrasite Spatial Analysis of the Cemeteries with Dispersed Cremation Burials

Marge Konsa

575 A Specific Approach for a Peculiar Site: New Spatial Technologies for Recording and Analysing a Palaeolithic Site (the Cave of La Garma, Northern Spain)

Alfredo Maximiano, Pablo Arias and Roberto Ontañón

584 Use of Quantitative Methods to Study an Alpine Rock Art Site: the Mont Bego Region

Thomas Huet

592 “The Whole is More than the Sum of its Parts”- Geospatial Data Integration, Visualisation and Analysis at the Roman Site of Ammaia (Marvão, Portugal)

Eleftheria Paliou and Cristina Corsi

608 Scattered Chronology - Surface Artefact Survey and Spatial Analysis of Ceramic Concentrations

Ondrej Malina and Jakub Silhavy

617 Ecological and Social Space in the High Mountains in South Norway 8500 – 2000 BP

Espen Uleberg and Ellen Anne Pedersen

624 Chalcolithic Territorial Patterns in Central Moldavia (Iași County, Romania)

Robin Brigand, Andrei Asăndulesei, Olivier Weller and Vasile Cotiuğă

636 Settlement Patterns in Drahaný Uplands (Czech Republic): GIS and Quantitative Methods Based Approach

Lukáš Holata

- 645 Rural Life in Protohistoric Italy: Using Integrated Spatial Data to Explore Protohistoric Settlement in the Sibaritide**
Kayt Armstrong and Martijn van Leusen
- 655 Reconstructing the Ancient Cultural Landscape Around Pompeii in 2D and 3D: from Scientific Data to a Computer Animated Museum Exhibit**
Sebastian Vogel, David Strebel, Michael Märker and Florian Seiler
- 662 Using GIS to Reconstruct the Roman Centuriated Landscape in the Low Padua Plain (Italy)**
Michele Matteazzi
- 670 Integrating Spatial Analyses into Foraging Societies Land Use Strategies. A Case Study from the Nalón River Basin (Asturias, North of Spain)**
Alejandro García, Miguel Angel Fano and Diego Garate
- 678 Lost Worlds: A Predictive Model to Locate Submerged Archaeological Sites in SE Alaska, USA**
Kelly R. Monteleone, E. James Dixon and Andrew D. Wickert
- 694 Familiar Road, Unfamiliar Ground. Archaeological Predictive Modelling in Hungary**
Gergely Padányi-Gulyás, Máté Stibrányi, Gábor Mesterházy and Márton Deák
- 710 Mathematical Models for the Determination of Archaeological Potential**
Nevio Dubbini and Gabriele Gattiglia
- 720 Calculating Accessibility**
Irmela Herzog
- 735 Simulated Paths, Real Paths? A Case Study of Iberian Cessetania (Iron Age Society)**
Joan Canela Gràcia
- 742 Open Source GIS for Archaeological Data: Two Case Studies from British and Egyptian Archaeology**
Anna Kathrin Hodgkinson, Luca Bianconi and Stefano Costa
- 752 Speeding up Georeferencing with Subpixel Accuracy**
Gianluca Cantoro
- 761 Multi+ or Manifold Geophysical Prospection?**
Apostolos Sarris
- 771 Managing Data from Multiple Sensors in an Interdisciplinary Research Cruise**
Øyvind Ødegård, Martin Ludvigsen, Geir Johnsen, Asgeir J. Sørensen, Stefan Ekehaug and Fredrik Dukan and Mark Moline
- 781 Towards Detection of Archaeological Objects in High-Resolution Remotely Sensed Images: the Silvretta Case Study**
Karsten Lambers and Igor Zingman

792 ArcheOS and UAVP, a Free and Open Source Platform for Remote Sensing: the Case Study of Monte S. Martino ai Campi of Riva del Garda (Italy)

Alessandro Bezzi, Luca Bezzi, Rupert Gietl and Nicoletta Pisu

800 The Visualization of the Archaeological Information through Web Servers: from Data Records on the Ground to Web Publication by Means of Web Map Services (WMS)

Julio Zancajo, Teresa Mostaza and Mercedes Farjas

Theoretical Approaches and Context of Archaeological Computing

807 Crafting Archaeological Methodologies: Suggesting Situational Method Engineering for the Humanities and Social Sciences

César Gonzalez-Perez and Charlotte Hug

821 Boundary Concepts For Studying the Built Environment. A Framework of Socio-Spatial Reasoning for Identifying and Operationalising Comparative Analytical Units in GIS

Benjamin Vis

839 Everything Flows: Computational Approaches To Fluid Landscapes

Dimitrij Mlekuž

846 Reliability of the Representation of a Distribution: a Case Study on Middle Bronze Age Metal Finds in the Seine Valley

Estelle Gauthier and Maréva Gabillot

854 Assessing Positional Uncertainty due to Polygon-to-Point Collapse in the Cartographic Modelling of Archaeological Scatters

Fernando Sanchez and Antoni Canals

863 Theoretical Space-Time Modelling of the Diffusion of Raw Materials and Manufactured Objects

Estelle Gauthier, Olivier Weller, Jessica Giraud, Robin Brigand, in collaboration with: Pierre Pétrequin and Maréva Gabillot

874 A Tangible Chronology

Jean-Yves Blaise and Iwona Dudek

888 Reconstructing Fragments: Shape Grammars and Archaeological Research

Myrsini Mamoli and Terry Knight

897 Grammar Modelling and the Visualisation of an Uncertain Past: the Case of Building 5 at Portus

Matthew Harrison, Simon Keay and Graeme Earl

912 Can Infovis Tools Support the Analysis of Spatio-Temporal Diffusion Patterns in Historic Architecture?

Jean-Yves Blaise and Iwona Dudek

926 History in 3D: New Virtualization Techniques for Innovative Architectural and Archaeological Scholarship and Education

James C. Sweet, Krupali Krusche, Christopher R. Sweet, and Paul Turner

939 Investigating the Effectiveness of Problem-Based Learning in 3D Virtual Worlds. A Preliminary Report on the Digital Hadrian's Villa Project

Lee Taylor-Nelms, Lynne A. Kvapil, John Fillwalk and Bernard Frischer

949 Building Blocks of the Lost Past: Game Engines and Inaccessible Archaeological Sites

Anna Maria Kotarba-Morley, Joe Sarsfield, Joe Hastings, John Bradshaw and Peter Nicholas Fiske

961 Re-reading the British Memorial: A Collaborative Documentation Project

Nicole Beale and Gareth Beale

Foreword

This volume is an extension of the printed volume “Archaeology in the Digital Era. Papers from the 40th Annual Conference of Computer Applications and Quantitative Methods in Archaeology (CAA), Southampton, 26-29 March 2012. It consists of a selection of the peer-reviewed papers presented at the Computer Applications and Quantitative Methods in Archaeology 2012 conference hosted by the Archaeological Computing Research Group at the University of Southampton, UK between 26th and 30th March 2012. The conference included 53 sessions divided between the themes of simulating the past, spatial analysis, data modelling and sharing, data analysis, management, integration and visualisation, geospatial technologies, field and lab recording, theoretical approaches and the context of archaeological computing, and a general theme. In addition there were 12 workshops. A total of 380 papers and posters were presented, and two key note addresses. Alongside the lively conference atmosphere at the venue there was a thriving social media back channel. In addition to these proceedings there is therefore a broad ranging multimedia record of the event, accessible via the conference website.

The co-organisers of CAA2012 and myself would like to thank the CAA Steering Committee for their advice and assistance. We are also indebted to Professor Anne Curry (Dean of Faculty of Humanities) and Professor Jonathan Adams (Head of Archaeology) for their support and encouragement. Many individuals and organisations in Southampton and further afield, including the sponsors and exhibitors, contributed to making the conference such a success. Of course without the many delegates travelling from across the globe and offering such exciting contributions there could have been no conference, and we are very grateful to them for their lively contributions to all aspects of the event. Finally, we would like to offer our thanks to the superb team of volunteers that made CAA2012 possible. The Archaeological Computing Research Group at Southampton was very proud indeed to be able to host the 40th CAA conference and we know that this was demonstrated by the enthusiasm, dedication and professionalism of the postgraduate and undergraduate students that gave so much of their time to the event.

I very much hope that you enjoy these proceedings and all the many related outputs from CAA2012, and I look forward to seeing you at future CAA conferences.

Graeme Earl

Southampton, United Kingdom, November 2012