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 toobtain 'quickly' the individual measures of every element whichcompose 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 theseimages, we applied techniques to enhance and improve, looking for toextract 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 measuringcells, thus contributing in the mensiochronology methodology that we try to apply at the study.

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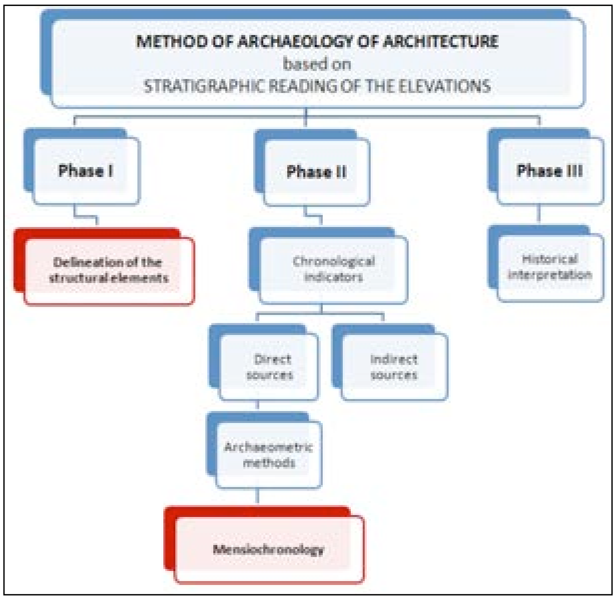


Figure 1. *Scheme of the method for Archaeology of Architecture. In red, phases in which the contributions of this methodology are developed.*

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 obtainthe 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 findin 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 ashlars, 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 ashlars. 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 ashlars 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

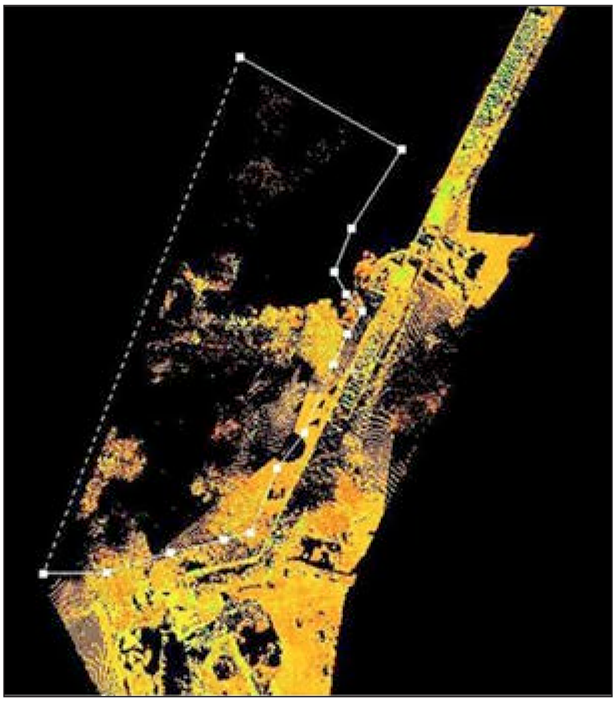


Figure 4. *The image shows one of the polygons through which cleaning is performed.*

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 itmay be complex because the masonry isnot 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.

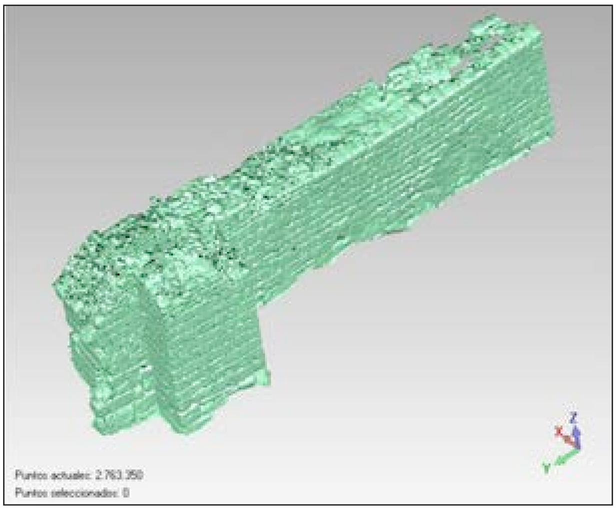


Figure 5. *Picture of outside of sub-area 7.1, loaded as .pts file format in Geomagic Studio software.*

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 manualform (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 .ptx 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

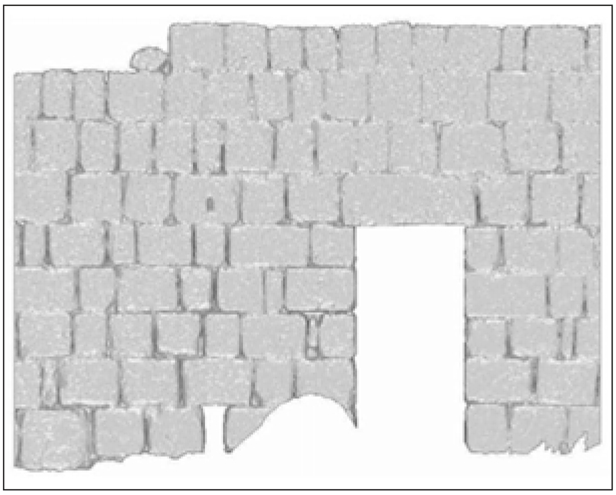


Figure 6. *Orthoimage of outside of subarea 4.1.*

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.Whichwas a product derived fromthe triangle mesh with a resolution of 96 pixels per inch, whose aims was toprovide 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, whichcame 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 removingresidual 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 ashlars and masonry were not entirely demarcated, for that we 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 ashlars, 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 ashlars 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 though to use this program to determine the width and height of

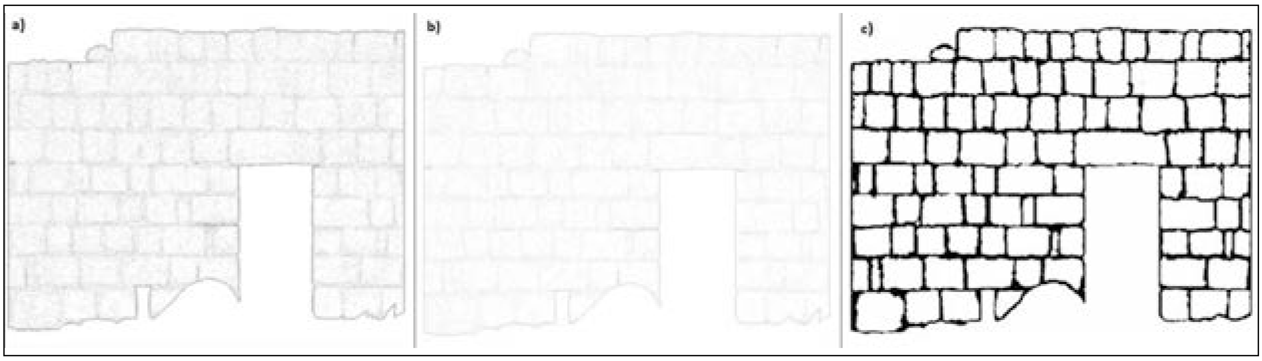


Figure 7. *Image of outside of Subzone 4.1 treated with a) 'Sobel filter', b) 'Laplace filter' and c) 'Tampon filter'.*

each element. One of the requirements of the program is towork 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 theyare 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).

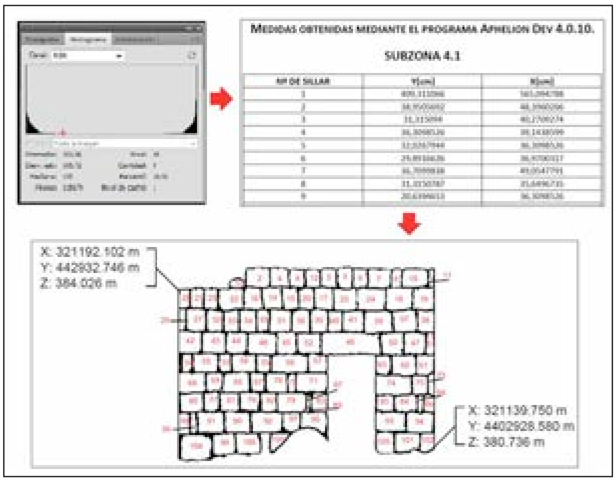


Figura 8. *Results of the classification and the dimensional measurements of structural elements in the outside of subarea 4.1.*

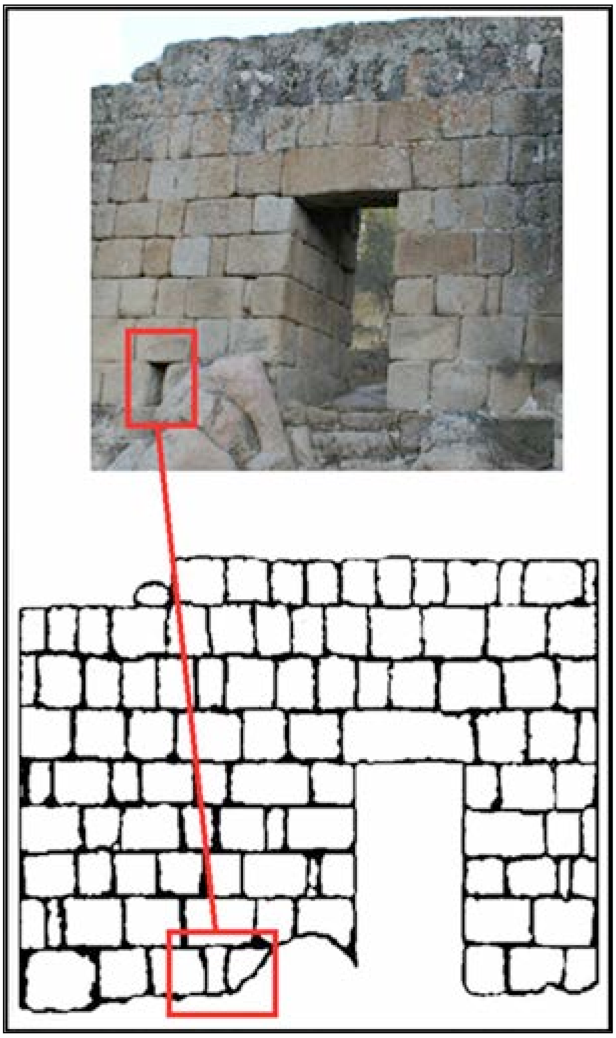
As the result, a table with the number of ashlars or masonry element and the height and width is obtained, necessary parameters to proceed to the temporal study by mensiochronology.

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 ashlars 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 visual perception (0.2 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, becauseitis 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 itcan be seen how residuals are distributed.



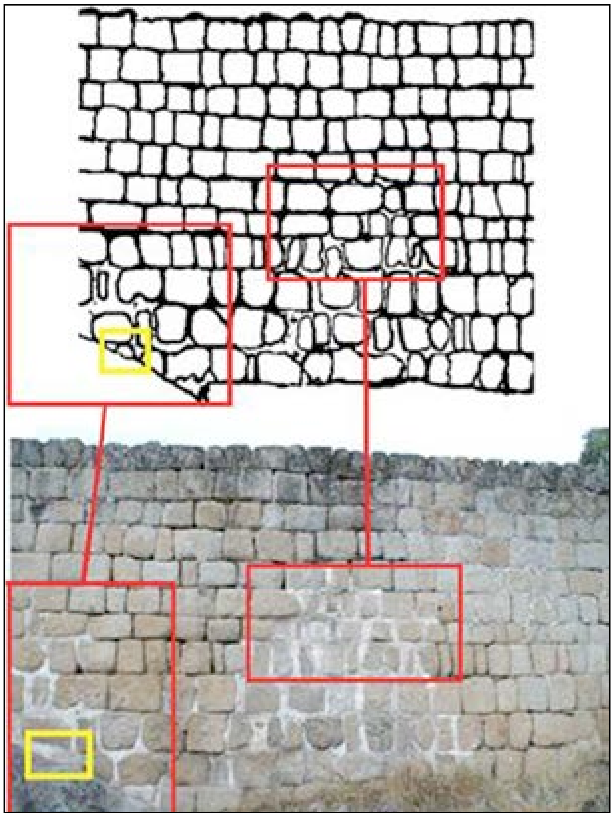


Figure 9. *Image of some of the main problems when trying to define different elements with that method. a) Waste pipes which had to be defined manually, b) Errors caused for the joints of lime mortar.*

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.

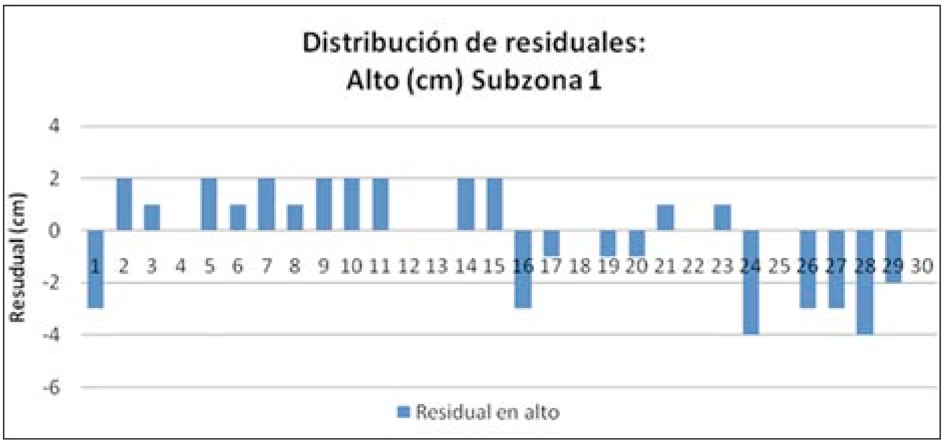


Figure 10. *Length remainders distribution in centimetres, Subzone 1.*

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 itcan 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
	HEIGTH	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
	HEIGTH	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
	HEIGTH	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.*

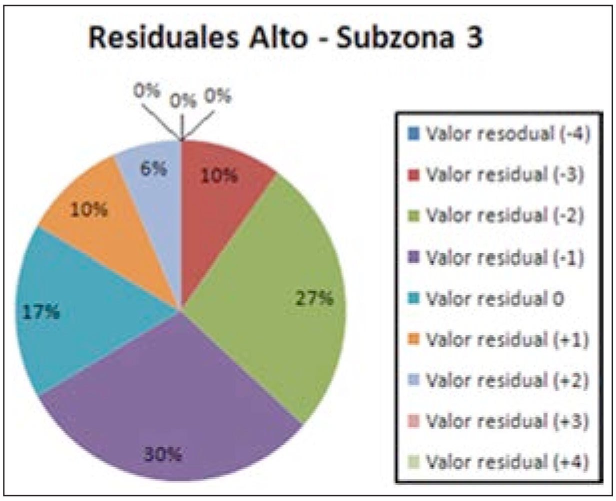


Figure 11. *Height remainders- subzone 3.*

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 chrono-typology. 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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Archaeology in the Digital Era
Volume II

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e-Papers from the 40th Conference on Computer Applications and Quantitative Methods in Archaeology

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Contents

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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