The effects of time constraint on 3D acquisition and data processing: the case of "Villa delle Vignacce"

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Abstract

Despite many technological and scientific advances, the methodology of 3D model reconstruction of an archaeological excavation can present some difficulties. One of these is represented by a time factor, which is often linked to economical issues. Time becomes an essential project constraint when there are survey restrictions or limitations in data processing. The temporal limits can lead to an important disjuncture between theoretical approaches and real results that can be obtained in a restricted time. Transferred into practice it means that a resolution-driven time frame approach can be applied only in projects with unlimited resources whereas a real situation often requires the application of a time-frame driven resolution methodology.

A key step is represented by the initial survey planning in which the determined areas of study directly affect the acquisition method, instruments utilized in the project, data processing and, in general, the amount of time necessary to complete the whole modelling project. The realistic evaluation of these relevant factors, once determined, are essential in order to obtain the best results of the scan in a particular, limited lapse of time.

The case study presented in this paper is the "Villa delle Vignacce" excavation, a 2nd century AD structure in the area now called the "Parco degli Acquedotti" investigated by the American Institute for Roman Culture. The necessity to rapidly close this excavation project area and a limited budget required a particular compressed 3D acquisition and processing procedure, so a different 3D survey and modelling approach was applied for the creation of a 3D model of a big portion of this case study.

The aim of the paper is to suggest a different planning approach for 3D acquisition and data processing in order to optimize time and costs and reach a good compromise between quality and quantity factors, obtaining the best model resolution compliant with a pre-assigned time-frame.

Key words*: 3D scanning, archaeological excavation, process optimization, project timing*

1 Introduction

In recent years some researchers have tried to understand the importance of the use of digital technology in the field of archaeology (AA.VV., 2000; Frischer et al., 2002) while the use of instruments and methods based on digital acquisition and visualization has become ever more relevant and commonplace. This diffusion is symptomatic of the increasing interest in the many advantages and uses of 2D and 3D digitalization system, databases, and computer graphics. They are used for acquisition and analysis of the original archaeological datum, archiving, sharing, dissemination, and reconstructive interpretation of objects that no longer exist and the networking of virtual models and information in a single information model.

Two technologies in particular have been developed and added to the typologies of traditional survey approaches: photogrammetry (Remondino et al., 2006) and 3D laser scanning (Blais, 2000) with relative benefits and drawbacks in their applications (Levoy et al., 2000; Bernardini et al., 2002). In recent years an important advance has been the study of the integration of survey methodologies and the definition of different 3D survey workflows optimized in relation to the characteristics of the physical model (Guidi et al., 2003; Beraldin, 2004). Attention has been directed to resolve the problems of different levels of resolution and the preservation of the trustworthiness of the datum. These are issues of

particular importance in the field of cultural heritage.
The advent of digital technology to the field of survey has profoundly changed the relationship between the artifact and the surveyor, whose responsibilities have been shifted. In the past, the surveyor focused on interpreting the cultural object and determining the quality of its representation. Today, since digital technologies can do both these things for the surveyor, the challenges he or she faces pertain more to accuracy of the data acquired (Guidi et al., 2004).
Although a reverse modelling process of cultural heritage artifacts or sites can no longer be considered a novelty, some bottlenecks and crucial factors are present inside a standard method that affect the correct definition of the final digital model.

2 Limitations in reverse pipeline

Projects of 3D acquisition and modelling in the field of archaeology field present some problematic aspects but only a few of these define the project development.
The first one concerns the instruments' performance: resolution, accuracy, uncertainly, acquisition time, field of view and work distance parameters represent instrument features that must be coherent with the geometrical and dimensional characteristics of the real model.
The second aspect is the morphological complexity of the physical model, which sometimes requires sensor fusion or integrated methodologies to address a cultural heritage subject.
Beyond these two aspects, some environmental factors can affect heavily a survey, modifing both the 3D acquisition parameters in terms of quality and the operator performances on site. Often elements like sun brightness, wind, heat of the sun, and bad weather conditions coexist with the use of instruments and the operator's work activity in a survey campaign at archeological site.
These aspects have to be considered and analyzed carefully during the planning for a survey. Beyond these factors that are normally faced, two other elements are present and essential to plan for a 3D acquisition and modelling process: limited budget and time control of the whole pipeline. In fact in a small case study the limitations of budget and time become critical aspects that clearly delimit the a project survey. These particular limitations oblige one to choose instruments and plan a process suited not for the geometrical characteristics of the pysical object as for time availability, trying to obtain the best data in terms of quality and quantity in a fixed amount of time.
This means that the methodology evolves from a theoretical approach, that consider the best survey method in relation with the cultural heritage object or site without any external limitations, into a real one, that must readapt itself inside a precise temporal or economical boundary.

3 Role of 3D acquisition and resolution in time-frame

In recent years complex archeological sites, such as the Forum of Pompeii (Guidi et al., 2009), Acropolis of Athens (El-Hakim et al., 2008) etc., have been focused on multi-resolution and sensor fusion aspects in order to improve the instrument performances, overcoming environmental problems. In these projects a resolution-driven time frame approach was applied, focused on a coherent representation of the complex archaeological systems. In these situations time and budget availability represented minor aspects within the whole project.
In contrast to these massive projects, small case-study budget and time limitations represent a real constraint for the planning and the development of the project. In this situation essential aspects like resolution in acquisition and modelling process have to be readapted to real time limitations. A different approach founded on time-frame driven resolution methodology can be suggested to solve these crucial aspects.
Recently, some research has focused on economical 3D acquisition and modelling system (Rocchini et al., 2001) or low cost methodology through sensor fusion (Russo et al., 2005).
However, in general, the optimization of time concerns not only the 3D acquisition step but also the whole pipeline. Therefore, the first question regards how much the scanning process and in general the acquisition step weight upon a reverse modeling process.
Some experimental results obtained in recent years about different reverse modeling project applied to

simple case-studies suggest that pure scanning time represents only a small part of the 3D survey step that, in turn, represents a limited part of the entire pipeline.

This consideration starts from the evidence that the 3D acquisition of the whole surface of an object in cultural heritage field normally obliges one to position the instrument in different positions, in order to cover the area from different points of view. Every shifting step involves the definition of the correct instrument position (which is not always simple and confortable), starting instrument and auto-calibration step, software and hardware set-up, the real scanning step and the closing session with recording data. This complex scheme must be repeated for every scanning point of view planned in the survey project.

For this reason that optimization of the number of instrument positions become essential in order to find the better temporal project evaluation.

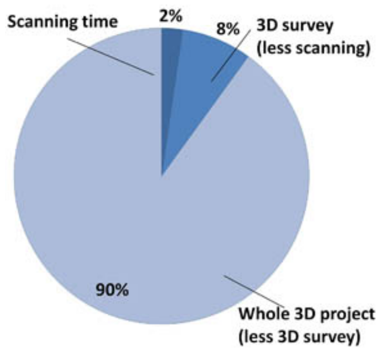

Figure 1. Pie chart on scanning time and in general 3D survey role inside a reverse project.

Obviously the ratio showed in Figure 1 can change if the survey project includes a large or complex structure. In these situations scanning time probabily gains a higher value due to the time left in acquiring a complex surface with high resolution.

The second question regards how resolution parameters modify the timeline of the project. In fact the choice of sampling step parameter during planning project affect not only 3D acquisition time frame but the whole process, involving other phases like alignment (cleaning step, computer processing) and post-processing (meshing, editing, optimizing).

A simulation of different approaches with two acquisition steps was carried out in order to understand this resolution role. A 20x20 meters area was surveyed with 5 cm and 5 mm resolution. The time results for the whole reverse process (acquisition, merge, editing and optimization step) show that a resolution variation of 10 time lead to an increase of 100 times of the whole time project.

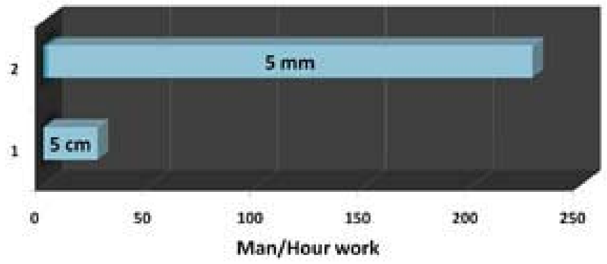

Figure 2. Histogram regarding length of time of two resolution approaches for the same area.

For this reason, the resolution choice has to be compliant with the geometrical characteristics of the physical model and has to be coherent also with the restrictions of project time imposed.

4 The case study: Villa delle Vignacce historical background

In 2006, the American Institute for Roman Culture (AIRC) and the Comune di Roma initiated an excavation of the “Villa delle Vignacce,” a well-known though virtually unexplored 2nd-century AD structure in the area now called the Parco degli Acquedotti (“Park of the Aqueducts”).

Figure 3. Excavation area of “Villa delle Vignacce”.

The "Villa delle Vignacce" ("Villa of the Vineyards") is a large suburban Roman structure to the south-east of Rome (de Franceschini 2005, Alteri 2005). Chronological evidence, in the form of brick-stamps (*CIL* XV 7534b) and building techniques, suggests that it was constructed in AD 125-130 with possible alterations in the 3rd-4th centuries, before it was destroyed perhaps in an earthquake. Recent excavation (seasons 2006-2008) has uncovered suggestive evidence of later occupation, perhaps in the Greco-Gothic Wars of the 530s.

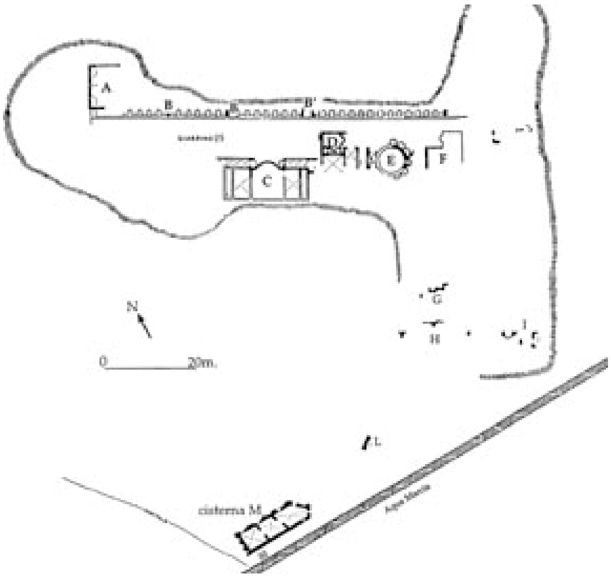

Figure 4. Plan of the visible remains of the "Villa delle Vignacce" by Ashby and Lugli (1928).

The site (Figure 4) sits on a raised artificial terrace (basis villae) adjacent to the arcades of the Marcia/Tepula/Julia aqueduct line (subsequently repaired and renamed Acqua Felice). The terrace is demarcated by noticeable drops in the terrain to the north-east and south-east. Several main elements of the structure can be discerned: a large nymphaeum-cistern (M) near the aqueducts, a range of buildings along the north-east terrace edge (C-F), an area of collapsed vaulting between these two areas which was revealed by excavation in 2006 to be a bathing complex, and a subsidiary set of cisterns at the northern edge of the north-east terrace (A).

Three seasons of excavation southeast of the standing remains of the hypothetical bath complex of the villa have revealed a previously undocumented bath complex (Figure 5) in the *suburbium* of impressive scale and quality of preservation.

Figure 5. Plan of the AIRC excavations at the "Villa delle Vignacce" by D. Cirone

The interpretation of the multiple phases of building is complicated by the absence of preserved stratigraphy, except in a few cases such as the drainage system. This is due to the fact that the buildings always remained in use, though substantially modified, over time, from the 1st to the 6th centuries AD. It is probable, though as yet unverified, that the remains excavated by AIRC are, in fact, part of the same bath complex identified in the Ashby-Lugli plan. It is also possible that the excavated structures were part of a massive villa, whose remains are yet to be identified, or it was, instead, an independent bath complex for the inhabitants of this area in the *suburbium*, unattached to any residential structure. Further excavations will resolve these hypotheses.

Figure 6. Detail of "opus sectile" in areas A7-8.

After three seasons, conservation concerns, budget limitations, safety issues, and maintenance constraints necessitated the closure of the excavation site and backfill the archeological area at the beginning of 2009. As a result, it was decided to create a brief scan of the site, as one more layer of documentation of the site "Villa delle Vignacce" with a 3D acquisition techinque, in order to record the geometrical information before closing the archeological excavation, presenting the final results of the entire project with these 3D data.

A limited budget and the time constraints due to the project deadline rendered this a suitable case study for a time-frame 3D reverse modeling application.

5 Survey approach

For an optimized project different aspects were considered. Initially, an order of survey precedence was defined, distinguishing which parts of the site were most important. This evaluation led to the creation of a survey priority map that shows the starting area of the scan and what could have been omitted if survey time finished.

Then, the 3D acquisition equipment availability was secured, in order to choose the best instrument in relation to the appropriate geometrical and dimensional characteristics of the site.

From satellite images the best a-priori instrument positions were planned, trying to optimize both the scanning area, avoiding redundant data not suited in this situation, and minimizing the time in evaluating the best position on site.

Finally, an acquisition sampling step was choosen in relation to the relevance of the different areas. This analysis led to a reference map shown in Figure 7.

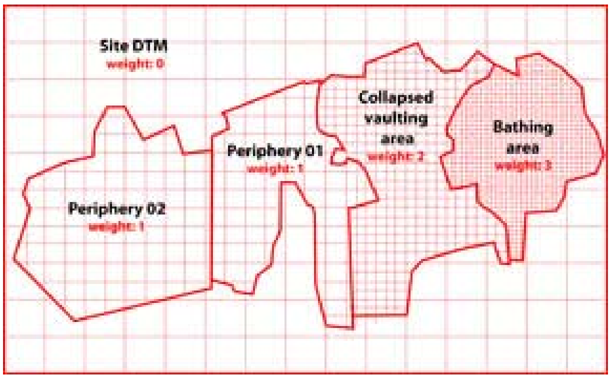

Figure 7. Weight map of the different site areas.

Range-data were acquired from the ground with a ToF sensor HDS3000 (Leica Geosystem) positioned in accordance with the survey planning project. To frame the whole surface and cover the relevant area 16 scanning position were necessary, 6 global scan with 2 cm of resolution and 10 detail ones with 5 cm of resolution.

The acquisition process normally consists of different actions that affect the whole time, like the equipment positioning, the instrumnet set-up, opening and closing connection (16 times for this project). Besides this we had to consider setting the instrument upon a trestle (6 times) and moving to uncomfortable survey equipment, conditions that takes more time than a normal set-up.

An a-priori analiysis on these aspects and the optimization of the instrument positions allowed us to conclude the acquisition in 7 hours, obtaining a better ratio of scanning time to acquisition step, from the standard 2:8 to 4:6.

It also shows the role that the scanning time plays the 3D acquisition process and the necessity to optimize not only the instrumental time but all the actions of this phase.

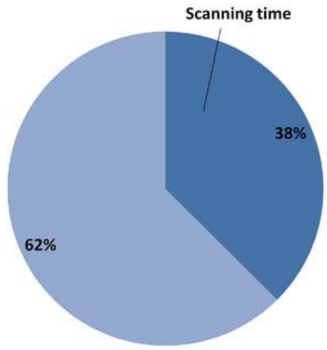

Figure 8. Pie chart on scanning time role inside 3D acquisition step.

The range data (ca 140 millions points) were processed inside Cyclone (Leica Geosystem), Polyworks (Innovmetric) and RapidForm (Inus Technology). The scans alignment (surface-based) and data editing (cleaning, layers generation, sampling and semantic subdivision of different structures) required ca 29 hours of work.
After cleaning, simplification and overlap reduction, 24 million points were useful for describing all the geometries in the site after 140 millions of raw data acquired (approx 1:6 reduction ratio).

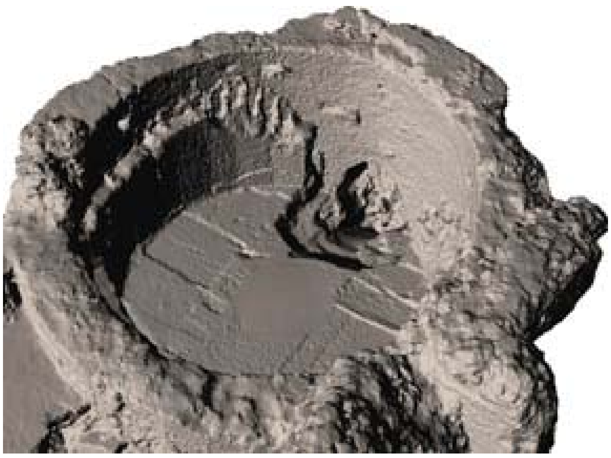

Figure 9. Portion of the high resolution model: the calidarium room

These data were used to create three different polygonal models characterized by different levels of detail:
- High resolution (only bathing area): 2 million polygons
- Middle resolution (complete area): 1 million polygons
- Low resolution (complete area): 500 k polygons

Time elapsed for data processing was 18 hours man/work.
Afterwards, the digital model was texturized. Maintaining time optimization as the goal of this project, was decided to texturize only few part (DTM and bathing area) of the low resolution model. This last step took 6 hours.

Figure 10. Part of the texturized model: view of the bathing area

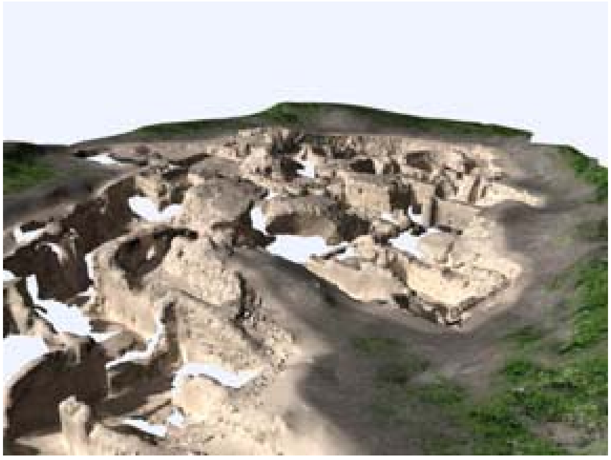

Figure 11. Global sight of the texturized model

6 Conclusion

Two important aspects were analyzed in relation to the bottlenecks present in a reverse modelling process applied to an archeological survey: time/budget constraint and the importance of the resolution parameter in the whole process.

A resolution-driven approach is typical of a complex survey project. But budget and time limitations often present in smaller project imply a different time-driven approch, based on the best optimization of the time-frame. Resolution choice conforms with this condition in accordance with the acquisition priority assigned to the different areas.

Besides this resolution choice deeply affects the whole project time-frame. This means that the sampling step must consider both the best solution compliant to the physical model and the project time constraints.

A time-driven approch and the right choice of resolution parameter lead to the optimization of time and costs, looking for the good compromise between quality and quantity factors, in order to obtain the best model resolution compliant with a pre-assigned time-frame.

At the end a case study suitable for this approach was shown, suggesting an optimized method (60 man/hours) to solve an archaeological site modeling with the little time and budget imposed.

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Bibliography

AA.VV., *Virtual Reality in Archaeology*, Edited by J.A. Barcelo, M. Forte and D.H.Sanders Oxford, ArcheoPress, 2000.

Alteri, R. “Villa delle Vignacce” in *Lexicon topographicum urbis Romae Suburbium*, vol. 3, pp. 179-181.

Ashby, T., Lugli, G., “La villa dei Flavi cristiani ‘ad duas lauros’ e il suburbano imperiale ad oriente di Roma,” *RendPontAcc* 2, 1928, pp. 157-192, tab. XXIII.

Beraldin, J-A., Integration of Laser Scanning and Close range Photogrammetry - the Last Decade and Beyond, in: *Proceedings of the XXth ISPRS congress, Commission VII*, Istanbul, Turkey, pp. 972-983, 2004.

Bernardini, F., Rushmeier, H., Martin, I.M., Mittleman, J., Taubin, G., Building a digital model of Michelangelo's Florentine Pieta, in: *IEEE Comput. Graph. Applicat.*, vol. 22, pp. 59-67, 2002.

Blais, F., Review of 20 Years of Range Sensor Development, *Journal of Electronic Imaging*, Vol 13-1, pp 231-240, 2004.

de Franceschini, M., *Ville dell'agro romano*, L'erma, 2005, pp. 197-202.

El-Hakim, S., Beraldin, J.-A., Remondino, F., Picard, M., Cournoyer, L., Baltsavias, M., Using terrestrial laser scanning and digital images for the 3D modelling of the Erechteion, Acropolis of Athens, in *Proc. of Digital Media and its Applications in Cultural Heritage (DMACH) Conference*, pp. 3-16, Amman, Jordan, 2008.

Frischer, B., Niccolucci, F., Ryan, N., Barceló, J.A., From CVR to CVRO: the Past, Present and Future of Cultural Virtual Reality, in: Franco Niccolucci editor, *Virtual Archaeology between Scientific Research and Territorial Marketing, proceedings of the VAST EuroConference*, Arezzo, Italy, 2002.

Guidi, G., Remondino, F., Russo, M., Menna, F., Rizzi, A., Ercoli, S., A multi-resolution methodology for the 3D modeling of large and complex archeological areas, in: *Special Issue in International Journal of Architectural Computing (IJAC)*, 2009, in print.

Guidi, G., Beraldin, J-A., Atzeni, C., High accuracy 3D modeling of Cultural Heritage: the digitizing of Donatello's "Maddalena", in: *IEEE Transactions on Image Processing*, Vol 13-3, pp 370-380, 2004.

Guidi, G., Beraldin, J-A., Ciofi, S., Atzeni, C., Fusion of range camera and photogrammetry: a systematic procedure for improving 3D models metric accuracy, in: *IEEE Transactions on Systems Man and Cybernetics Part B-Cybernetics*, Vol 33-4, pp 667-676, 2003.

Levoy, M., Rusinkiewicz, S., Ginzton, M., Ginsberg, J., Pulli, K., Koller, D., Anderson, S., Shade, J., Curless, B., Pereira, L., Davis, J., and Fulk, D., The digital Michelangelo project: 3D scanning of large statues, in: *Proceedings of the ACM SIGGRAPH Conference on Computer Graphics*. 2000.

Remondino, F., El-Hakim, S.F., Image-Based 3D Modeling: A review, in *The Photogrammetric Record Journal*, Vol.21 (115), pp.269-291, 2006.

Rocchini, C., Cignoni, P., Montani, C., Pingi, P., Scopigno, R., A low cost 3D scanner based on structured light, in: A. Chalmers, T.-M. Rhyne (Eds.), *EG 2001 Proceedings*, Vol. 20 (3), Blackwell Publishing, Oxford, 2001, pp. 299–308, 2001.

Russo, M., Guidi, G., Morlando, G., Low cost characterization of 3D laser scanners, In: *Proceedings of the Videometrics IX, IS&T/SPIE Symposium Electronic Imaging*, San Josè Convention Center, California, USA, 28 gennaio – 1 febbraio, 2007.