LOW COST DIGITAL PHOTOGRAMMETRY FOR UNDERWATER ARCHAEOLOGICAL SITE SURVEY AND ARTIFACT ISERTION. THE CASE STUDY OF THE DOLIA WRECK IN SECCHE DELLA MELORIA-LIVORNO-ITALIA.

Marco Canciani*, Pamela Gambogi **, Felice G. Romano**, Giacomo Cannata*, Pierre Drap***

*Universita' degli Studi Roma Tre, Dipartimento di Progettazione e Studio dell' Architettura, "Laboratorio di Rappresentazione grafica", ROMA, canciani@uniroma3.it
** Italian Ministry of Culture Ministero per i Beni e le Attività Culturali Soprintendenza per i Beni Archeologici della Toscana Firenze, Italy, sat@comune.firenze.it
*** MAP-GAMSAU umr CNRS 694, Marseille, France Pierre.Drap@gamsau.archi.fr

ISPRS Commission V, WG IV.
intercommission III/V

KEY WORDS: Underwater Photogrammetry, Marine Archaeology, VRML, XML, archaeological typology.

ABSTRACT:

In the frame of the new '*CIPA, Heritage, Documentation*' task group dedicated to underwater photogrammetry three laboratories from different disciplines have started to work together. We present here a work in progress on an underwater excavation of a Roman imperial wreck located in *Secche della Meloria,* in front of Livorno, Italy.
Secche della Meloria have always represented a tough peril for sailing, but also a due passage in Northwestern Tyrrenian courses, with a particular regard for those around *Portus Pisanus*. The surveys led by *Soprintendenza per i Beni Archeologici della Toscana (Nucleo Operativo Subacqueo)* from 1993 to nowadays, enabled to localize two Roman imperial wrecks (among the other findings), conventionally named *Meloria B* and *C*, or *Dolia Wreck* and *Marbles Wreck*.
The *Dolia Wreck,* situated at the center of the *Secche*, shows a concentration of *dolia* wall and lip fragments spread on about 9x6 meters area, part on the sand bottom and part hidden by *posidonia* (*Posidonia oceanica*) bushes at 6 meters depth. The larger fragments concentration is placed close by the *posidonia*, whose roots reach 2 meters height, maybe hiding part of the cargo load; other *dolia* large fragments have been found under a thin sand layer, close by the *posidonia*. Hull plank wooden elements showed up under a lip fragment; they seem to be also under the ware concentration.
The *Soprintendenza per i Beni Archeologici della Toscana* is starting the archaeological excavation with a three-dimensional modeling program of this site. Three main goals were followed in this work.
The first one is to record data before the next step of the excavation, which will be surely destructive. The photogrammetric approach is particularly relevant by the use of both geometrical data and qualitative data coming from the use of the photograph.
The second goal is to insert, in the three D model obtained, three D representation of some *dolia* large fragments currently not present on the site for different reasons and, on the other hand, to insert some representation of entire *dolia* funded both on some measured fragment and archaeological hypothesis regarding the *dolia* classification.
The third goal is to obtain a three D representation of the site usable as an interface between geometrical representation and a large set of archaeological data.

1. INTRODUCTION

The work is presented in several steps:

- The photogrammetric campaign, with a brief description of the low cost camera and the way used to take the picture.
- The bundle adjustment phase and the generation of DTM with photo mapping.
- The survey of *dolia* fragments *in situ* with the use of a specific photogrammetric software dedicated to the survey of archaeological artifact.
- The survey of *dolia* fragments previously tacked off the site, this is a normal terrestrial survey.
- The theoretical 3D model generation of the different *dolia* present on the cargo according to the present *dolia* classification validated by archaeologists.
- The merge of different 3D model, coming from different photogrammetric survey or model generation.
- The VRML generation of measured object and the merge

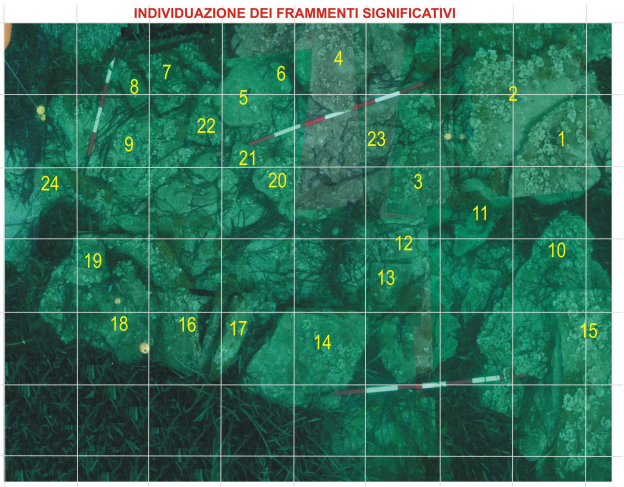

Fig.1 Photomosaic of the entire site of 'Meloria B' with VRML ground representation coming from DTM phase.

The results as archaeological as graphical are available on the underwater photogrammetric task group of *CIPA, Heritage, Documentation*' : http://cipa-uwp.gamsau.archi.fr

2. ARCHAEOLOGICAL CONTEXT

2.1 The Meloria wrecks

Secche della Meloria, just off the *Livorno* coast (and actually characterized by a depth ranging from 2,5 to 6 meters) have always represented a tough peril for sailing (Mistral, West, South-west and South-east winds), but also a due passage in

Northwestern Tyrrenian courses, with a particular regard for those around *Portus Pisanus*. As a consequence, the quantity of verified ancient wrecks is remarkable, constituted both by isolated findings and by the presence of large groups of cargo.

The surveys led by *Soprintendenza per i Beni Archeologici della Toscana (Nucleo Operativo Subacqueo)* from 1993 until now, enabled to localize two roman imperial wrecks (among the other findings), conventionally named *Meloria B* and *C*, or *Dolia Wreck* and *Marbles Wreck*. The two archeological underwater sites, very near to each other and both exposed to wave action, were visited frequently by thieves. Because of the low depth, the ancient shipbuilders may have tried to take materials away from the sites using *urinatores*, fishermen who dived to limit the losses originated by shipwrecks.

2.2 The Meloria B wreck

Situated at the center of the *Secche*, the site shows a concentration of *dolia* wall and lip fragments spread out on an area of approximately 9x6 meters, part of which is on the sand bottom and part is hidden by *posidonia* (*Posidonia oceanica*) bushes at a 5-6 meters depth. The larger concentration of fragments is located nearby the *posidonia*, whose roots reach a 2 meters height, maybe hiding part of the cargo load; other large *dolia* fragments have been found under a thin sand layer, close to the *posidonia*.

Hull plank wooden elements were found under a lip fragment; they seem to be also under the ware concentration. Originally four lip fragments were evident, some of which were covered by sand, and all characterized by a similar shape. In the summer of 2000, two of these large fragments were taken from Nucleo Sommozzatori Guardia di Finanza, for the purpose of preventing the eventual looting of the archaeological site; and they are actually conserved in the Tullio Santini barrack in Livorno.

Depending on the number of lip fragments and measures it's possible to calculate a minimum quantity of at least two medium sized *dolia*. Presently, factory stamps haven't been recognized, but macroscopic analyses of the clay refer to production areas located in ancient *Campania* and *Latium*. On some fragments swallow-tailed lead clamps are visible, which were used as a rule during the Roman age to strengthen or repair these large wine containers. *Dressel* 2-4 Hispanic amphorae small fragments and a *Dressel* 20 lip come from the site too. Only stratigraphic excavation of the site could bring definitive results: from preliminary data the wreck seems to belong to the kind of the trading ships specialized in carrying wine with very big *dolia,* during the first imperial age.

The first layer of fragments now visible cannot be restituted with the traditional graphic survey because of the enormous quantity of fragments and the position of the site in the open sea. To gather the data, numerous and successive dives are needed to take underwater measurements from a point zero, which can be subjected to human error.

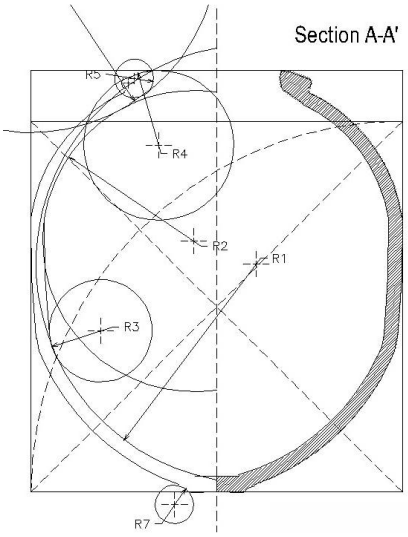

Fig.2 Reconstruction of the geometric description of a dolium.

2.3 The artefact model

The geometrical structural model of a dolium.

With regard to wreck B, as above mentioned, a number of dolia fragments of different sizes have been found, as a result of complete fragmentation of the load due to shipwreck. These large pottery containers are not of a definite kind, with

variable shapes ranging from globular to ovoid ones.
Here it appears we are dealing with dolia having elongated shape; this kind of shape was determined by survey and geometrical description, using traditional techniques for the measurement of fragments that were brought to land from the underwater deposit, and computer-based techniques for complete virtual elaboration of the model.
The geometrical description allowed for the determination of through the following steps: first, the fragment was measured, so as to determine its curvature (i.e., profile) and, consequently, its dimensions (**fig.2**); thereafter, geometrical description allowed for the determination of its shape and classification into a definite kind, based on comparisons with known dolia. By these techniques, it was possible to determine that this object was 207 cm high with an internal diameter of about 62 cm at the lip level.
The geometrical structural study on the dolium fragment not only allowed to define its complete profile, but also made it possible to carry out a metric-proportional analysis, which ruled out the existence of a module for the making of these objects. Indeed, the analyzed dolium cannot be inscribed into any simple geometrical figure, nor was it determined by canonic rules of proportion.
The 3D representation of this object provided information on its profile allowing, through rotation in space, to hypothesize its shape which was believed to be an ovoid-lengthened one, with a distinct shoulder, flat ring lip and a leveled bottom. In particular, the 3D representation of this fragment first, and of the whole object thereafter, was obtained using CAD software, which made possible a virtual representation of this object by elaborating on the information obtained from traditional survey.
Moreover, the fragment was double-checked using photogrammetry, and some useful differences must be pointed out. First, with regard to traditional survey, 3D representation of an object is obtained indirectly. Indeed, the fragment profile is first graphically reconstructed in 2D, and then the profile of the entire dolium can be graphically in the same way. With regard to photogrammetry, this technique directly yields the 3D model in space by directly acquiring data from the actual object, which is then elaborated on. Moreover, photogrammetry may be preferable in certain contexts. Indeed, since it may not always be easy to handle large fragments, as in this case, the traditional survey may be difficult to perform. On the other hand, photogrammetry allows one to acquire useful information directly from digital pictures.

2.1 Taxonomy Elaboration

The document management system proposed in this work is relying upon the hypothesis of the existence a theoretical model of the archaeological objects studied. In our case we can suggest a theoretical model for these objects.
This regularity in the production of the dolia allows us to use a modeling approach and to formalize this knowledge into a hierarchy of objects sharing the same properties and structured according to the Object paradigm.

3. PHOTOGRAMMETRIC SURVEY

3.1 The site survey

A photogrammetry and three-dimensional modeling program on the site was started in 2001 by *SBAToscana* (Nucleo Operativo Subacqueo - Pamela Gambogi, Felice G. Romano) in cooperation with Marco Canciani and Giacomo Cannata from
University of *Roma 3* (Italy) and Pierre Drap from *CNRS 694*, *Marseille* (France).
The purpose is to obtain more precise models than the traditional graphic surveys that are more costly and are now rarely used for underwater sites. Underwater surveying is not very accurate and is time consuming, which makes it inconvenient for underwater work.
The purpose is to obtain more precise models than the traditional graphic surveys that are more costly and are now rarely used for underwater sites. Underwater surveying is not very accurate and is time consuming, which makes it inconvenient for underwater work.
We decided to use a very simple and cheap way : digital Nikon Coolpix 990 in a Ikelite housing, "aerial photography" type for the survey, and Photomodeler software for the orientation and plotting phase. We make the survey thanks to Rolland Graille, professional diver from the CNRS "Centre d'oceanologie de Marseille", France, who came to help us with his competence and material.

3.1.1 Orientation

The selected method was to minimize the time of intervention. A set of rulers to put the model in scale and several buoys for vertical reference. (The buoys were made with some perforated table tennis balls).

3.1.2 Calibration

We decide to use a very simple way to calibrate the camera : the PhotoModeler calibration module. We just considered the set housing-camera rigid and indeformable and we made a calibration as if we were in air. The pin-cushion distortion is here modelized by focal length variation (increase) and radial distortion.
The model is useful, especially for the first layer (US 0) of the site, because it allows for the complete removal of the fragments for either the reconstruction of the original *dolia*, or to continue with the research below the first layer (US 1).
In the summer of 2001, in only three days of diving, about one hundred good quality digital photographs were obtained (the
water was of crystal transparency), after the calibration of the camera, to control the distortion and the effects of refraction in the liquid. From the strictly archaeological point of view the photographic system offers advantages of sure precision, of immediate viewing of the model and its many parts, and of the acceptable model adherence to the real physical appearance of underwater sites.

3.2 The on site Fragment survey

The survey of site 'Meloria B' has been carried out by a

series of underwater shots done with metric camera …and its case… through a process already used for site 'Meloria C', 'marble wreck'[Canciani, Gambogi, Drap, 2002], with shrewdness useful to minimize survey error's spreads, to simplify and speed up the restitution process.

To simplify and organize the photogrammetric restitution, a photomosaic has been done, on a first approximation, realizing a photographic map covering the complete site (**fig.1**).

The model points traced by the restitution have been about 400, with an approximation of 1%, referring an average of 6 points on at least 4 adjoining photos, in order to stabilize the returned model.

In this phase it has been preferred to simplify the model to make it more easy to handle and adaptable to the only arrangement of the dolia fragments still in site, tessellating the surface points.

These have been classified, as indicated by photomosaic, by software Arpenteur ,[Drap, Grussenmeyer, 2000], importing the wireframe model from software Photomodeler, using the orientations calculated by the photo shots. The model has been even more elaborated with R.O.M.A., procedure by Arpenteur, to obtain a dynamic visualisation, adapting the textures derived by the underwater shootings.

The diversity of the objects handled by the archaeologist and the geometric complexity of their surfaces led us to search for stable morphological characteristics of the objects where diagnostic measurements could be taken. A series of simple geometric primitives are used to approximate these morphological characteristics and are used as an interface between the photogrammetric measurement and the underlying model.

The geometrical description of the class makes up a list of attributes, definition of the position and orientation (translation, rotation matrix) and definition of the geometrical characteristics: height, diameter of the collar, diameter of the paunch, etc.

As the measurement and the management of the dolia of this wreck are based on strongly incomplete data sources we focuses the survey on fragment measuring. A fragment typology .was elaborated and integrated in the general underlying model. This typology is accessible from the Arpenteur survey windows, dedicated to the Dolia survey.

A more complete 3D representation can be generated according to the basic photogrammetric measurement and the theoretical model. The merge operation of both these two sources is manage by a rule engine. [Drap, Seinturier, Long, 2003].

The accessibility of information produced thanks to the model which browses on the web, linking on every object recognized by the virtual site (dolia fragments, in big part), a series of xml files with the relative specifications (dimensional, historical, descriptive) **fig.3**.

3.3 The external fragment survey

In 2003, at Livorno barrack Tullio Santini, a photogrammetric survey of two big fragments, discovered in 2000 in the 'Dolia wreck' site, has been carried out according to the most popular photogrammetry procedures, [Canciani, Maestri, Spadafora, 2001].

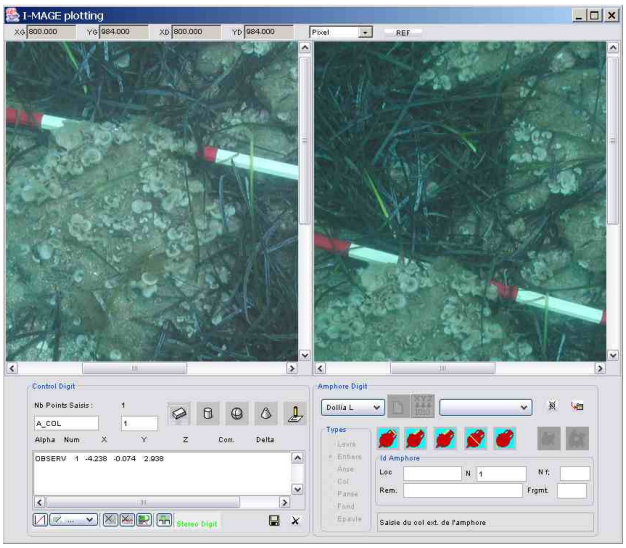

Fig. 3 Arpenteur digit windows, dedicated to fragment dolium survey.

Through these procedures it has been possible to carry out a very accurate restitution respect to the depth survey (less more 1400 points, with a thoroughness of 0,075 %), an exact definition of the fragment's geometry (rotation axis, maximum and minimum diameter, internal and external diameter of the lip), and a characterisation of the surface through the textures acquired by the photographs.

A comparison has been possible to draw between the textured fragment and the model defined according to the reconstructive hypothesis done by the archaeologists (realized on the basis of the traditional direct survey of the

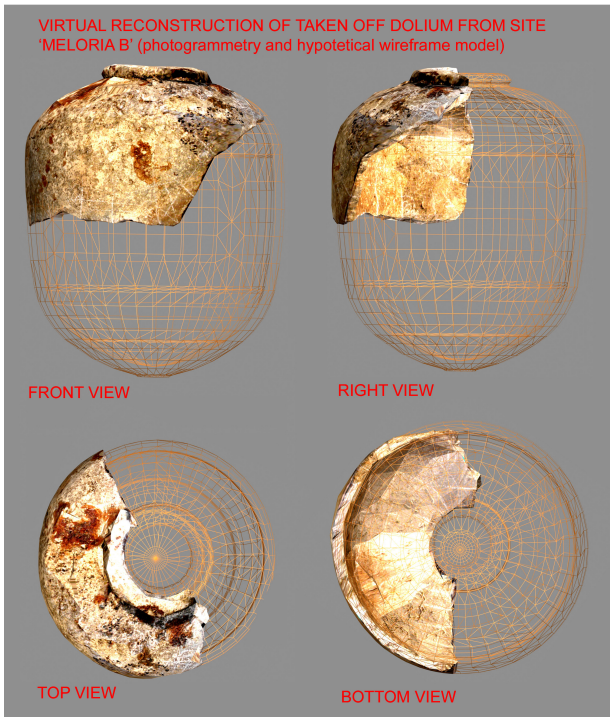

Fig.4 3d model textured by photogrammetry mixed with reconstructive wireframed model.

generic section) **fig.4**.
It has been possible in this way, to verify the congruence of the model reconstructed with the photogrammetric survey directly on the final mixed model, allowing a vrml browse in accordance
with predefined views: frontal, lateral, planimetric, etc.
The problems occurred have concerned mostly the restitution model, which has been divided in its internal and external part
and reassembled through photo shots of the lateral edges, whereas on the lip areas of the dolium, a gathering of more possible points has been tried, above all in correspondence of the characteristic section.

3.4 Archive photograph to relocate the fragment as it was

To finally obtain the US 0's complete restitution on January 2003 photogrammetric survey was computed from the fragments transported to the ground in 2000. The pieces were relocated in the exact position as they were found when submerged by means of virtual pictures (their position was determined by photograph shot at the moment of discovery with the site under control). The relocating of the large fragments in the bottom of the sea to fit in their exact position was strenuous and difficult. It is obvious in this particular case that virtual reconstruction would be advantageous.
To obtain merging between the various restitutions, underwater shootings taken in 2000 have been used, before the resumption of bigger fragments.
Through about 30 points recognized in common on this sequence of photographs and those shot in depth in 2001, it has been possible to fit in the same orientation the fragment model and the depth one, realizing in this way a merging between the two models and a virtual reconstruction of the original site.

4. RESULTS AND CONCLUSION

4.1 Visualization and Interaction

The importance of the visualization of a three-dimensional model for archaeology at the scale of archaeological object needs no longer to be demonstrated. For instance, see Paul Reilly from 1990 in an article entitled "Towards a virtual archaeology" published in the Computer Applications in Archaeology conference proceedings in Southampton, which clearly described the interest in the elaboration of a three-dimensional model and its visualization. Since then, this aspect has largely been studied and many theoretical studies on the 'reconstruction' of the past have been undertaken. On this subject see the synthesis of Juan A. Barceló [Barceló, 2000].

4.1.1 The Limitations of VRML

The VRML three-dimensional imaging language is well adapted to simplified and quick visualization. Coupled with a script language such as PHP, it also allows a simple and efficient link to a relational DBMS for consultation or an XML database access. Within these limits of use, it fulfils perfectly its job and research projects which employ it, for example, the virtual museum project dedicated to the evolution of a city developed by Maria Elena Bonfigli and Antonella Guidazzoli [Bonfigli, Guidazzoli, 2000]. It is also used with a sound JAVA 2D interface, such as the educational work in the GIS from Kate Moore, Jason Dykes and Jo Wood at the University of Leicester, [Moore, Dykes, Wood, 1997]. Nevertheless, VRML suffers from a lack of portability, the fact that free and efficient viewer hasn't been developed for Unix, and especially from an enormous lack of flexibility for dynamic updating of three-dimensional models.

4.1.2 The Opening of JAVA 3D

Since the version 2 of Java (Java 1.2 and Java 1.3), a three-dimensional graphic library is available. Like VRML, JAVA 3D offers an imaging graph and a clear structure in the represented space. The JAVA 3D designers are involved in the development of VRML and offer a series of bridges and translators between these formats (mainly in VRML / JAVA3D).

Obvious advantages of JAVA 3D on VRML rest in two directions:

- JAVA 3D is a JAVA library and can therefore be used directly from the model development language. The link between the graphic representation and the model becomes then intimately close and it is possible to easily consider a bidirectional link between the model and its graphic representation, also between a persistent object manager, the acting object and its graphic representation.
- The visualization of imaging is no longer linked to a three-dimensional tool which is unusual, not really portable and no longer dependent on the JAVA 3D library on the host computer. JAVA 3D is distributed for a majority of today's computer systems.

We are currently developing a set of mechanisms, based on object approach to offer to objects a dynamic behaviour for their graphic representation. This approach will also allow visualization on the web of relations linking the objects.

4.2 XML and a patrimonial Information System

The data management, an omnipresent problem in

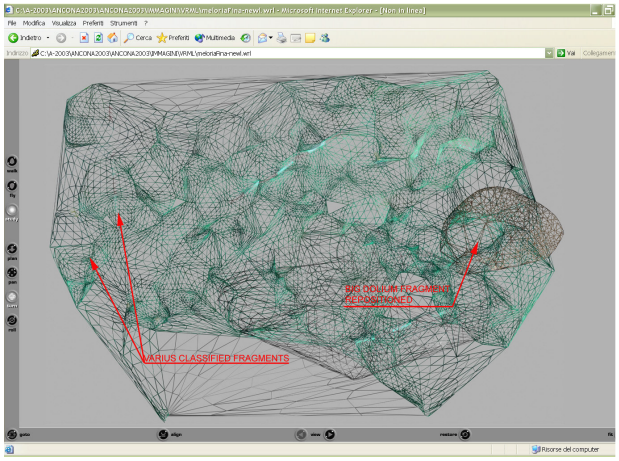

fig.9 Vrml view of wireframed model of the site with all dolium fragments.

archaeology, is dealt in two ways: the first one is purely textual and the second is based on the object geo-referential point-of-view. These two approaches are accessible on the Internet.

The three-dimensional model as an interface to the data formalized in XML allows the purely documentary data (references, observations made during the excavation, photographs) to be linked to a three-dimensional representation of the object. This graphic expression of the object relies on the data (position, orientation, dimensions) and on the generic knowledge of the object (theoretical shape, default values, relationships between various objects, facts and computation needed). The three-dimensional model, generated by the system, shows the generic model of the object, defined by the archaeologist, measured by photogrammetry and thereby a relevant interface between the user and the collected data.

In this framework of multimedia data management system, our objective is to publish the data in different ways, XML is the choice we made to federate them. Thanks to this formalism we can represent in an homogeneous way a set of very different kinds of data such as structural description of the image content, physical data, photogrammetric data.

The result data, generated in XML, allows both a simple and automatic publication of the result towards different media, and a way to elaborate a request on the whole set of data.

5. REFERENCES

References from Journals:

[Drap, Grussenmeyer, 2000] Drap P., Grussenmeyer P. 2000. A digital photogrammetric workstation on the web. Journal of Photogrammetry and Remote Sensing, 55(1): 48-58.

References from Other Literature:

[Barceló, 2000] Juan A. Barceló " Visualizing what might be. An introduction to virtual reality techniques in archaeology." VIRTUAL REALITY IN ARCHAEOLOGY, Edited by Juan A. Barceló, Donald Sanders, Maurizio Forte. Published by Archéopress PO Box 920 Oxforf OX27YH, 2000.

[Bargagliotti, Cibecchini, Gambogi, 1996] S. Bargagliotti, F. Cibecchini, P. Gambogi, Prospezioni subacquee sulle Secche della Meloria (LI*):alcuni risultati preliminari, in Atti del Convegno nazionale di archeologia subacquea*, (Anzio, 30-31 maggio-1 giugno 1996), S. Spirito (Ba) 1997, 43-53.

[Bargagliotti, Cibecchini, Gambogi, 1997] S. Bargagliotti, F. Cibecchini, P. Gambogi, Prospezioni subacquee sulle Secche della Meloria (LI*):alcuni risultati preliminari, in Atti del Convegno nazionale di archeologia subacquea*, (Anzio, 30-31 maggio-1 giugno 1996), S. Spirito (Ba) 1997, 43-53.

[Bargagliotti, Cibecchini, 1998] S. Bargagliotti, F. Cibecchini, *Le Secche della Meloria, in Memorie Sommerse, Archeologia subacquea in Toscana*, Porto S. Stefano (Gr) 1997, catalogo della mostra (a cura di G. Poggesi, P. Rendini), Pitigliano (Gr)1998, 176-183.

[Bargagliotti, 1998] S. Bargagliotti, *Rinvenimenti sottomarini di età imperiale sulle Secche della Meloria. Risultati delle campagne di ricognizione* 1993-1998, in Archeologia subacquea. Studi, ricerche e documenti, III, Roma.

[Bonfigli, Guidazzoli, 2000] Maria Elena Bonfigli, Antonella Guidazzoli, " A www virtual museum for improving the knowledge of the history of a city" VIRTUAL REALITY IN ARCHAEOLOGY, Edited by Juan A. Barceló, Donald Sanders, Maurizio Forte. Published by Archéopress PO Box 920 Oxforf OX27YH, 2000.

[Canciani, Maestri, Spadafora, 2001] "*Archaeological Survey: Data Processing Experimentation and Direct Observations*" in the proceedings of International Symposisium CIPA 2001 "Surveying and Documentation of Historic Buildings - Monuments - Sites Traditional and Modern Methods", Potsdam, Germany 2001.

[Canciani, Gambogi, Drap, 2002] Marco Canciani, Pamela Gambogi, Pierre Drap, *"Web archaeological data management system from underwater photogrammetry. An application on*

two roman wrecks". ISPRS, Commission V, Close Range visualization techniques, 2 -6 September 2002, Corfu, Greece. to be printed.

[Drap, Seinturier, Long 2003] Pierre Drap, Julien Seinturier, Luc Long "*Archaeological 3D Modelling using digital photogrammetry and Expert System. The case study of Etruscan amphorae*". 3ia'2003 conference. The fifth international conference on computer graphics and artificial intelligence. Limoges (france), 14 - 15 of may, 2003. to be published.

[Drap, Bruno, Long, Durand, Grussenmeyer, 2002] Pierre Drap, Emmanuel Bruno, Luc Long, Anne Durand,Pierre Grussenmeyer; " Underwater photogrammetry and xml based documentation system: The case of the 'Grand Ribaud F' estruscan wreck", ISPRS COMMISSION V SYMPOSIUM Close-Range Imaging, Long-Range Vision 2-6 September, 2002, Corfu, Greece.

[Pensabene 1972] P. Pensabene, Considerazioni sul trasporto *di manufatti marmorei in età imperiale a Roma e in altri centri occidental*, in Dialoghi di Archeologia, III serie, 1, 1972, 323-324.

[Rendini,1991] P. Rendini, *La prima età imperiale: i relitti con dolia, in Relitti di storia*, Archeologia subacquea in Maremma, Grosseto 1991, catalogo della mostra (a cura di M. Celuzza, P. Rendini), Siena 1991, 85-89.

[Ciampoltrini, Rendini, 1996] G. Ciampoltrini, P. Rendini, Un dolio di P. RO[CIUS-] POMP. *Nuovi ritrovamenti dall'Arcipelago toscano*, , (Anzio, 30-31 maggio-1 giugno 1996), S. Spirito (Ba) 1997,, 55-61.

References from websites:

[Cipa-uwp, 2002] The web site of CIPA-Documentation underwater photogrammetric task group http://cipa-uwp.gamsau.archi.fr