LOW COST SYSTEM FOR VISUALIZATION AND EXHIBITION OF POTTERY FINDS IN ARCHEOLOGICAL MUSEUMS.

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Abstract

The objective of this project is to build a low-cost system for surveying, modeling, prototyping and interactive visualizing aimed at the enhancement of islamic pottery finds of X – XI centuries. The system will allow various applications: the creation of systems for displaying artifacts from the museum alongside the exhibition, the virtual view of restorations from fragments, including AR and VR, the physical reconstruction of the original form using 3D printer to show the pieces in their entirety, as well as the construction of interactive virtual archives to be made available to scholars and visitors.

Keywords

Virtual exhibition, Rapid Prototyping, new system of exhibit, Islamic Pottery

1. Introduction

The project was born from a collaboration between the Department of Architecture of the University and the Antonino Salinas Archaeological Museum of Palermo[1]: its objective is a low-cost system for survey, modeling, prototyping and interactive visualization aimed at the enhancement of archaeological finds, as well as for the realization of storage and exposure systems, both virtual and phisical.

The pilot project was formulated for the exhibition of some of Islamic pottery dating between the second half of the tenth century and the first half of the eleventh century.

The first stage is aimed at obtaining a 3D model from a points cloud, to be used later in various ways. The first one is to build a virtual database of the museum's pieces and make them visible through virtual exhibitions. A second application is designed to use the 3D model information and integrate them with traditional archaeological studies, in order to reconstruct the original shape of the object.

The reconstructed model can integrate the virtual exhibition of the finds, and allow the visitor to review its conjectural reconstruction, in an interactive way.

The 3D model of the reconstruction may become also the basis for the construction of a physical model through rapid prototyping, to be used for exhibition.

The part of the digital model, necessary for virtual integration, can finally be used for the full view of the object in Virtual or Augmented Reality, through smatphones or tablet.

The methods of virtual exhibition are designed to be accessible both online and offline, in situ, using the touch screen or totem. to be offered as an integrated system of on-site exhibition[2].

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[1] Thanks to the availability of the Director of the Museum, Dr. Francesca Spatafora.

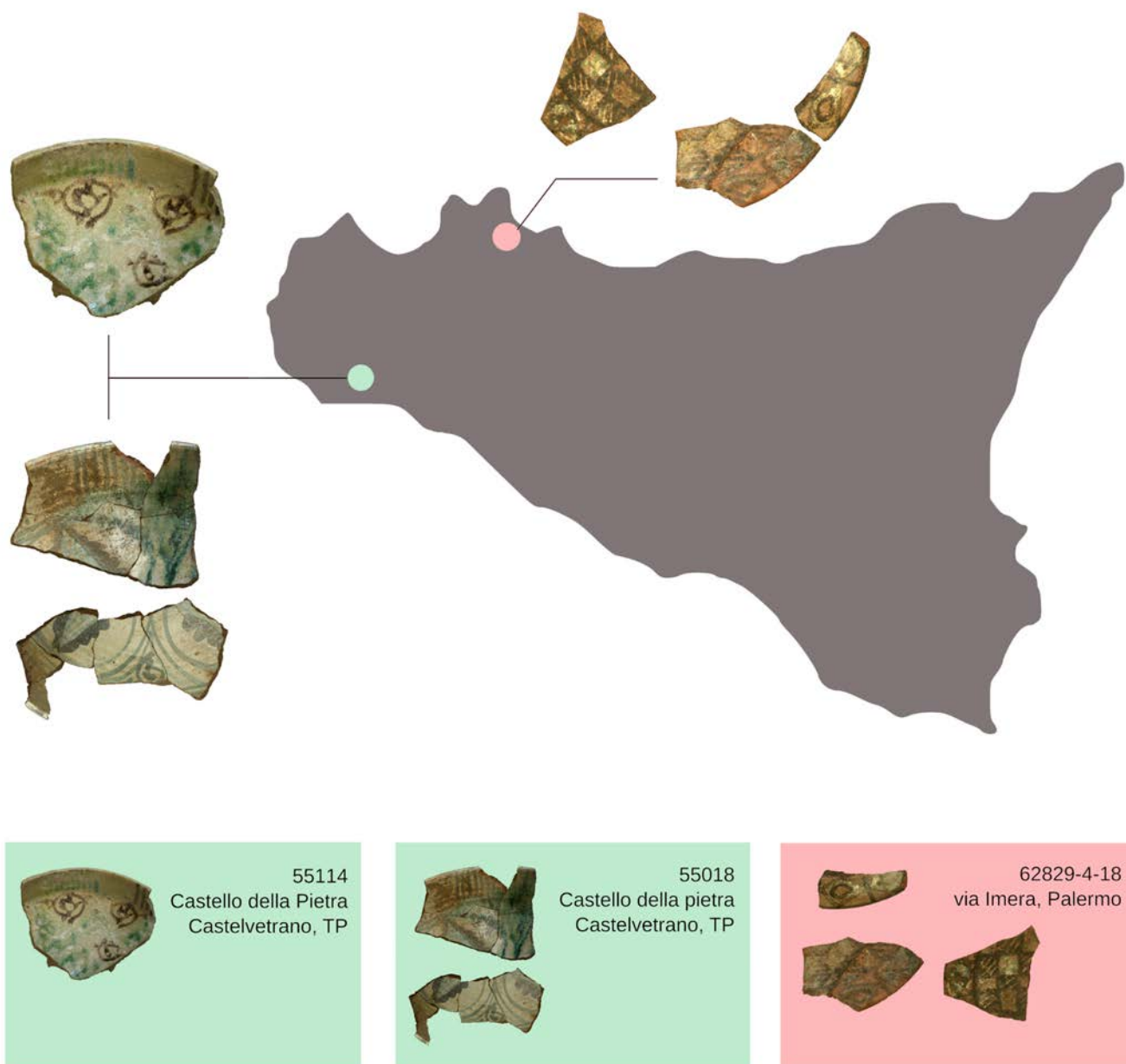[2] The introduction was written by Fabrizio Avella, coordinator of the project.

Fig. 1: The pottery fragments and their geographical sites .

2. Three Islamic potteries from Via Himera (PA) and Castello della Pietra (TP)

Before describing the potteries object of this study, it is important to briefly offer some news about the historical background of the Islamic age of Sicily and the state of art of the studies concerning the pottery of this period. It is of the utmost importance to face, even though shortly, this last aspect because it will be clear why it is so

difficult to propose chronologies of the Islamic pottery of Sicily.

2.1 Brief history of Islamic Sicily

The history of Sicily of the Islamic age is known thanks to few written sources, some contemporary and some later to the narrated events, which describe different aspects of the island. Ibn al-At̲īr (1160-1233), in his chronicle

entitled *al-Kāmil fi'l-tā'rīkh* (*The Complete History*), described the most important events which happened in Sicily before, during and after the Islamic conquest of the island.

From about 652, Sicily started to suffer from Muslims' raids, which were turned into a real conquest campaign in 827 by the Aghlabids (800-909), a dynasty of Ifrīqiyan governors. Initiated by the landing of Muslims forces at Mazara (827), thanks to a military campaign encouraged and organized by the Aghlabids[3], the conquest was completed in about 150 years, after the fall of Messina (976). Known in the texts as *Balarm*, *al-Madīna* and even *Ṣiqilliyya* (probably an abbreviation of *Madīnat al-Ṣiqilliyya*, "Sicily's

The studies on the history of Islamic Sicily also suffer an objective scarcity of written sources, even if recent new interpretations of these sources demonstrate that there still are many data which can be obtained[5]. Given the limits of the written sources, the only way to increase our knowledge of Sicily's history is to address other type of sources.

The pottery, which is the most widespread finding in archaeological excavation, is one of these, even if it poses some problems. Until recently, archaeological contexts of the Islamic period were dated with glazed pottery in a generic way from the second half of the 10th to the beginning of the 11th century, on the basis of a
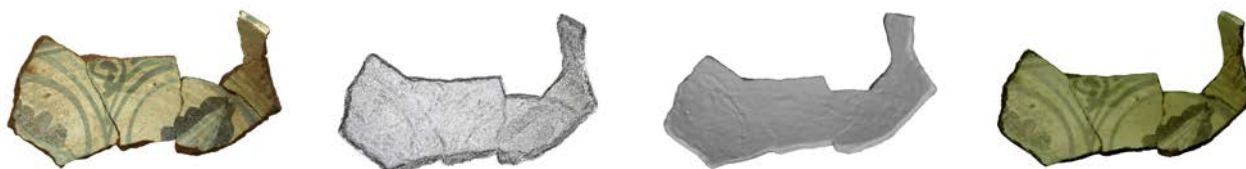

Fig. 2: Fragment N.I. 55018 – From left to right: the photo, the points cloud, the polygonal mesh, the 3D model with color information .

city"), Palermo became the capital of Sicily - whereas in the Byzantine period it was Syracuse – and a remarkable urban expansion took place.

The Islamic period of Sicily's history consists in the succession of three dynasties: the Aghlabids of Ifrīqiya (827-909), the Fatimids (909-1040) and the Kalbids who, from 948 to 1040, ruled on behalf of the Fatimids. The end of the Islamic domination of Sicily took place between 1061 and 1091, when Robert and Roger of Hauteville conquered Sicily.

2.2 Brief state of art of the Islamic pottery in Sicily

The state of art has a number of problems, which in recent years have been well analysed by academics[4]. For example, concerning the history, too many studies still do not contextualize Islamic Sicily and Palermo in the broader frame of the *dār-al Islām* ("the Land of Islam"), and conceive them rather as a part of "Italy" in a quite teleological way.

comparison with the famous Pisan bacini[6]. Therefore not only was the dating unclear, but it was also surprisingly late if we consider that the Islamic conquest of Sicily began in the first half of the 9th century. It suggested that, for a century or more, nothing changed in Sicilian ceramics and that the newcomers did not use glazed ceramics in Sicily[7]. Fortunately, recent studies[8] questioned this monolithic vision of a uniform and "timeless" Islamic period and tried to characterize the constant transformations which affected the material culture of Palermo during the two centuries of Islamic domination.

Today we cannot but observe that for the Islamic period of Sicily, our knowledge of the potteries produced and imported in the island is extremely patchy and the chronology of these materials tentative at best. If the situation is improving for the end of the 9th century and the first half of the 10th century[9], the pottery of the second half of 10th – first half of 11th is still

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[3] (Nef, 2011).
[4] Cf. expecially (Nef , & Prigent, 2006); (Arcifa, Bagnera, & Nef, 2012); (Ardizzone, & Nef, 2014).

[5] (Nef, & Prigent, 2006).
[6] (Berti, & Tongiorgi,1981).
[7] As justly pointed out by Bagnera A., cf. (Arcifa, Bagnera, & Nef, 2012).
[8] Most of which in (Ardizzone, & Nef, 2014).
[9] Cf. (Ardizzone, & Nef, 2014).

classified without more precision, in a monolithic way, and the transition periods (Byzantine/Islamic and Islamic/Norman) remain obscure. Moreover not all ceramic classes are known in the same way, and some of these are very few identified. In conclusion it is of the utmost importance to carry out much more studies on the Islamic pottery of Sicily and a revision of ceramics indicators.

2.3 Description of the pottery

The potteries studied in this project has been found in two different archaeological sites: Via Himera in Palermo (N.I. 62829) and Castello della Pietra (Trapani) (N.I. 55114 and 55018). They are all glazed pottery dated to the Islamic period[10].

The N.I. 62829[11] is a plate of 22 cm of diameter characterized by a green and brown decoration covered by a transparent colourless glaze, probably a lead glaze. The decoration consists in a chessboard, which is a very widespread motive during the Islamic period.

It can be proposed a chronology in the 10th century, even if there is some uncertainty. Even the place of production is not totally clear. Only scientific analyses can clarify if this plate has been produced in Palermo.

The N.I. 55114[12] is a carinated bowl with a bifid vertical rim characterized by a green and brown decoration covered by an opaque colourless glaze.

We don't know if the opacity is the effect of the deterioration of the glaze or it is a desired effect. The decoration is realized with green and brown decoration painted with equal thickness which draw a sort of circles and vertical bars. This bowl seems to be an Ifrīqiyan production and it can be dated in the first half of 11th century.

The N.I. 55018[13] is a carinated bowl with a bifid vertical rim characterized by a green and brown decoration and a deteriorated glaze. The decoration consist of phytomorphic motifs enclosed in circles in the central part, and by vertical bars in the highest part of the bowl. The provenance of this bowl is uncertain, but we can exclude that is a Palermitan production. Also in

this case the chronology can be establish at the first half of 11th century[14].

3. The sample finds in the framework of the new layout of the Antonino Salinas Archaeological Museum

The finds from the Islamic age, used as samples within the project for structuring a low-cost system for survey, modelling, prototyping and interactive viewing, were selected among those destined for the new layout of the medieval section of the Antonino Salinas Museum in Palermo.

They are three lead-glazed open forms: a dish (N.I. 62829, cf. supra Sacco, published in Agrò 2014, p.51, p. 48 fig. 3, n. 18) recovered, during an emergency excavation carried out in 1980 in Via Imera in Palermo, in a cavity (silo D) used as a rubbish dump[15]; and two carinated bowls (N.I. 55114 published by F. D'Angelo[16]; N.I. 55018 unpublished cf. supra Viva Sacco) recovered during the digging campaigns carried out in 1973-1974 at Castello della Pietra (Trapani province) in a cavity used as a rubbish dump[17].

The finds from both sites originate from domestic tips, i.e. from what archaeologists consider a precious source "able to furnish very detailed qualitative and quantitative information on the material culture of an epoch and a settlement"[18]. The collection of items recovered from the Via Imera rubbish dumps (during an emergency excavation) and from Castello della Pietra (during an archaeological investigation concerned with the most ancient phases of the site) in effect constitutes a remarkable historical testimony making it possible to reconstruct, and to display for future visitors to the Museum, the ceramic outfit used in the Islamic age in two sites that are deeply different for quality and size of the settlement.

The numerous finds from silo D in Via Imera very probably represent the ceramics circulating in some homes in the capital of the emirate of Sicily, between the first Islamic age and the end of

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[10] For the description of the archaeological sites cf. *infra*.
[11] This sherd has been published in (Ardizzone, & Agrò, 2014).
[12] (D'Angelo, 1997).
[13] Unpublished.

[14] Paragraph n. 2 is entirely wiritten by Viva Sacco.
[15] (Ardizzone, & Agrò, 2014).
F. Ardizzone, F. Agrò, L'islamizzazione a Palermo attraverso una rilettura della ceramica da fuoco dei butti di via Imera, in (Ardizzone, & Nef, 2014).
[16] (D'Angelo, 1997).
[17] (Ardizzone, D'Angelo, Pezzini, & Sacco, 2012).
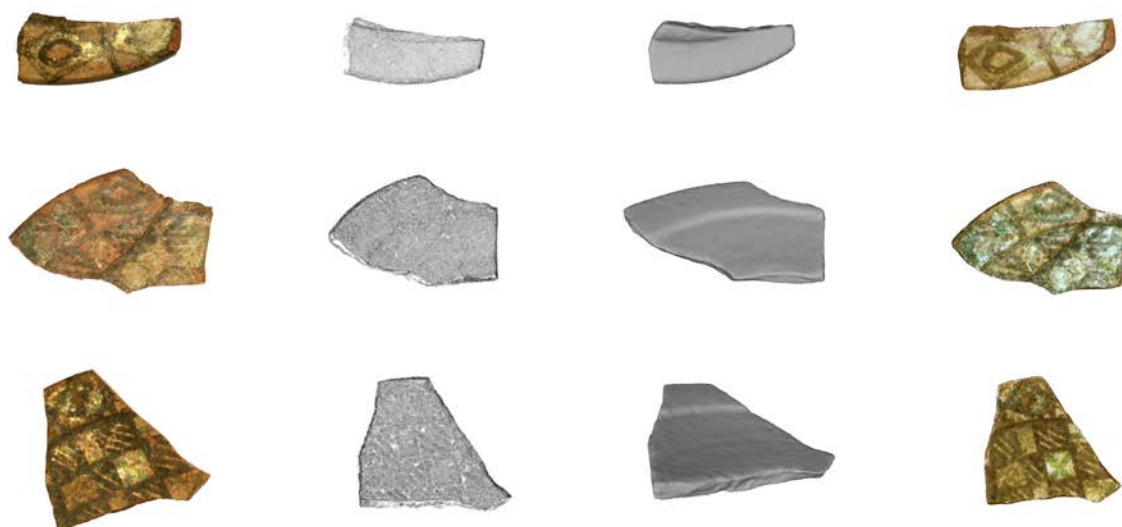[18] (Manacorda, 1984).

Fig. 3: The fragments N.I 62829-4-18. From left to right: the photo, the points cloud, the polygonal mesh, the 3D model with color information.

the 10th century. The materials from Castello della Pietra instead illustrate the ceramics used, between the second half of the 10th century and the beginnings of the 11th, that is to say in the Kalbid age, in a fortified site, near the south coast of Sicily, positioned to control the valley of the river Belice, an important route of penetration.

The material recovered in the two rubbish dumps renders immediately perceivable the daily life of these sites in the Islamic age and yields information on the commercial relationships, the economic life and finally on the social sphere of Islamic Sicily, integrating what we know from the written sources (cf. supra Sacco). It is therefore necessary in the new layout for the single ceramics to be displayed in such a way as to valorise to the utmost their information potential; that is to say, they should be immediately recognizable from the functional point of view and their decoration should be legible. Finally, it is important that some ceramics can be enjoyed from the aesthetic point of view since these are craft products of some merit.

Precisely to restore legibility to them, many of the materials from the two tips have been restored but the fragments selected for application of polygonal modelling techniques pose some peculiar problems. Specifically, the dish from Via Imera N.I. 62829 and the bowl from Castello della Pietra N.I. 55018 are constituted by several fragments that are not contiguous and therefore it is not possible to put them together

again. It therefore seemed interesting to test above all on these ceramics the survey project because it appeared to be possible to have two complementary products and can be submitted to different applications: virtual 3D reconstruction of the pieces and 3D printing of the filling of the gaps in the pieces themselves.

3.1 3D printing of the filling of the gaps.

The creation with 3D printing of the filling of gaps in the pieces is a system that certainly requires further tweaking but proves promising because of its total and immediate reversibility. Substantially, a test was carried out on basin N.I. 55114 regarding the possibility of constructing a filling/support to complete the piece from the morphological viewpoint, immediately making its function evident and restoring it to its original dimensions. At the same time, precisely because it is not welded to the piece, the filling is immediately removable; it is therefore possible at any moment to have the fragment available with its fracture surfaces for possible demands linked to scientific investigations. This is an operation that traditional fillings, reversible but modelled with adherence to the fragments, do not make it possible to carry out, except through removal of the filling itself.

The limit of this system lies in the material and in the quality of the surfaces of the filling. Filling glazed medieval ceramics with polychrome

decoration is a complex action, for which different methodologies have been worked out and different solutions can be adopted. To guarantee full enjoyment of the find, depending on the cases and the methodological orientation chosen, the filling can take on a colour harmonised with the background fabric or with the colour of the glaze or with the colours of the decoration.

Finally, for some pieces of particular merit or for particular display demands, it may be preferable to reproduce the decoration of the piece on the filling, naturally with a system that makes it immediately recognizable as a restoration[19]. Hence the filling/support created with the 3D printer must be submitted to further manual action by a restorer.

3.2 Virtual 3D reconstruction and interactive viewing

Complementary to the physical reconstruction of the piece, which in some cases is necessary for display purposes, is virtual 3D reconstruction and interactive viewing. This is an extremely versatile tool that can have different possibilities of application both for study purposes, and for museum display, as well as for valorization of the museum's collections.

In the museum the visitor through a q-code can have access to the virtual reconstruction, or to several proposed reconstructions, of the ceramics. This is a solution that could be undertaken for pieces for which non-contiguous fragments are preserved, like dish N.I. 62829 from Via Imera and carenated bowl N.I. 55018 from Castello della Pietra. In the showcase the fragments not put together could be displayed but it will be possible to see in augmented or virtual reality one or more proposals of reconstruction that restore the piece in its morphological and decorative integrity. Naturally, using the same technique it will be possible for the visitor, in virtual reality, to access material from the same contexts that it is not possible to display for reasons for space. In this way the interested visitor can have full information on the collection of ceramics yielded by the site with all its information potential.

Lastly, an archive of 3D virtual reconstructions, integrated in a divulgation programme like the one that at the moment the Museum is developing through social media, can become a remarkable tool of communication with the outside world, that is of "socialization", through the web, of the collections of the Museum[20].

4. Description of the process

The entire process is the result of subsequent phases of work: data acquisition and processing, generation of polygonal meshes, 3D modeling, rapid prototyping and optimization of the model finish, systems for Virtual Reality and Augmented Reality.The entire chain was built using open source software and low-cost systems.

4.1 Data acquisition

The first phase involves the acquisition of metric, formal and chromatic data, thanks to a process of simplified photogrammetry.

The methodology used, belonging to Close Range Photogrammetry category, is based on a Image Based Modeling (IBM) process and uses the technique of Structure From Motion (SFM)[21], which allows the recognition of homologous points on a cluster of images belonging to the same photografic session[22].

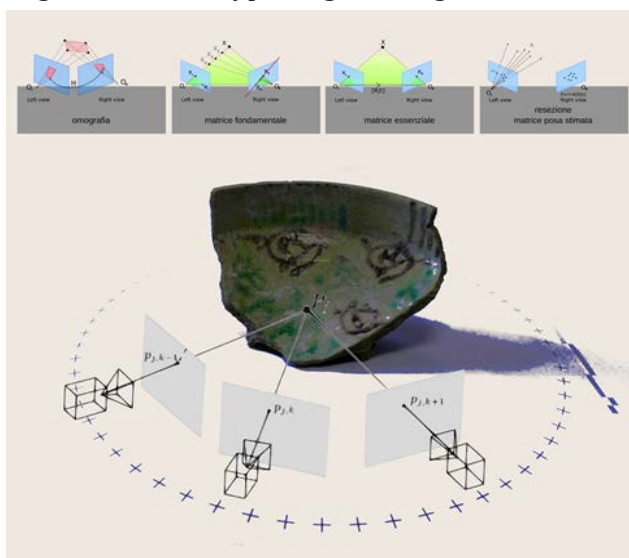The photographs were taken with a not metric digital camera, type Digital Single Lens Reflex

Fig. 4: Scheme for the photographic setting.

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[19] On the different methods for filling gaps in the glazed medieval ceramics see (Bonetti, Lanterna, Michelucci, & Tosini, 2000).

[20] Paragraph n. 3 is written by Francesca Spatafora and Elena Pezzini.
[21] (Bezzi, & Bezzi, 2010).
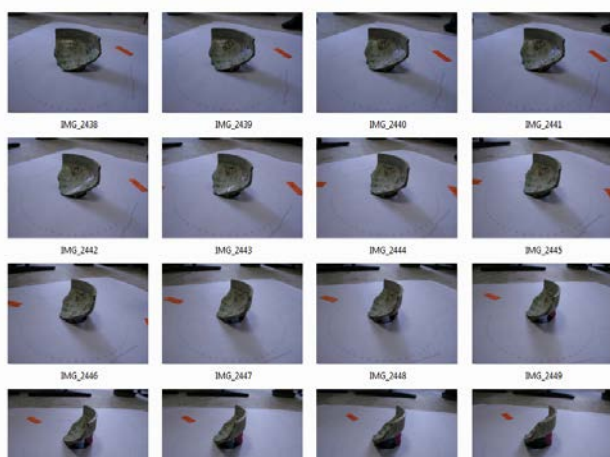[22] About SFM see: (Torres, Arroyo, Romo, & De Haro, 2012).

Fig. 5: Some photos of the cluster.

(DSLR), of entry-level category.

The size of the fragments allowed photographic sets in rooms of small dimensions. The exhibits were positioned at the center of an A0 format board, specially designed, which served as a guide to determine the number of poses, from 32 to 64 for each piece, depending on

Each exemplar was photographed on both sides so as to obtain point clouds that, in the next step, consented the full reconstruction of the piece.

The first phase was concluded with the construction of photo cluster, from which it was possible to generate and manage Spares Point Clouds, with Open Source systems such as Python Photogrammetry Toolbox (PPT) and Bundler.

4.2 Data processing, mesh generation and 3D modeling.

The next step was that one relating to the collimation of the point clouds and polygon meshes generation.

The collimation, obtained using at least four pairs of homologous points, allowed the rotation, the translation and the scaling of point clouds obtained from different clasters related to the fragment. Once the point cloud is obtained subsequently thanks to a process of cleaning of all the points of the surrounding environment and of those ones constituting noise[23].
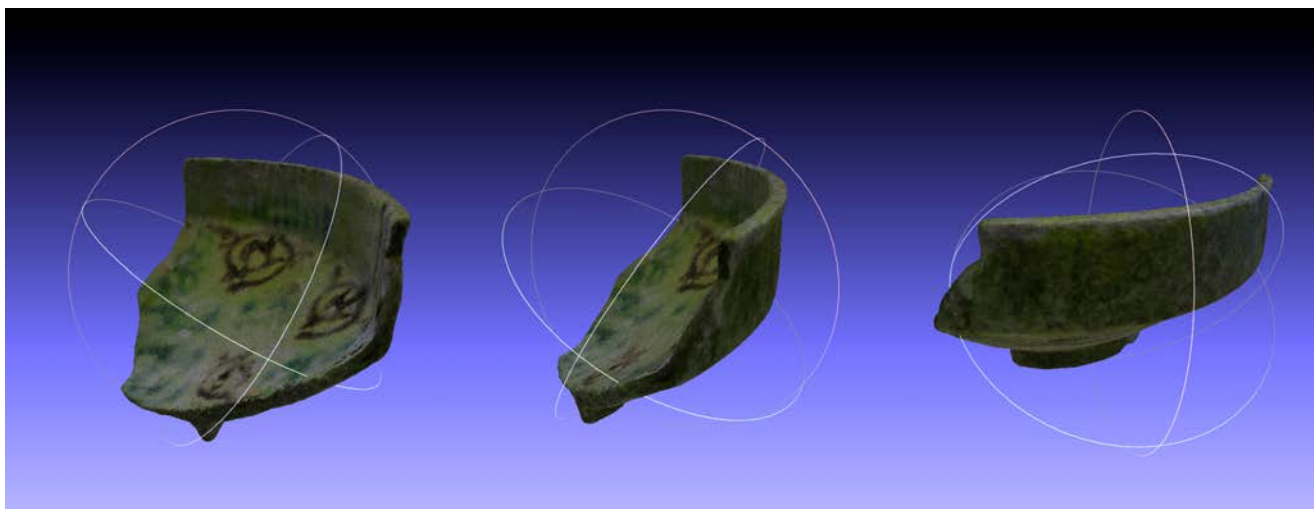

Fig. 6: Fragment N.I. 55114, views of the 3D model with color information.

the level of precision that is wanted to obtain.

It was made a lot of attention to lighting conditions, avoiding too strong contrasts on the piece, and taking care not to produce annoying reflections in those exhibits that has a layer of glaze. To optimize the quality of photos we set the ISO sensitivity to 100, to eliminate noise resulting from higher values, and we tried to keep the aperture values to the values as F/18 or lower, to increase the depth of field.

The focal length has always been higher than 55 mm, to avoid distortions of a wide angle lens.

The mesh obtained in this way was subsequently optimized, eliminating gaps and regularizing the normal.

The process of retopology is necessary to optimize the mesh and make it homogeneous for both operations prototyping and operations texturing. The last one need the uniform distribution of the normals to the surface.

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[23] About point clouds density and mesh optimization, also if applied in another field of application, see (Falkingham, 2012).
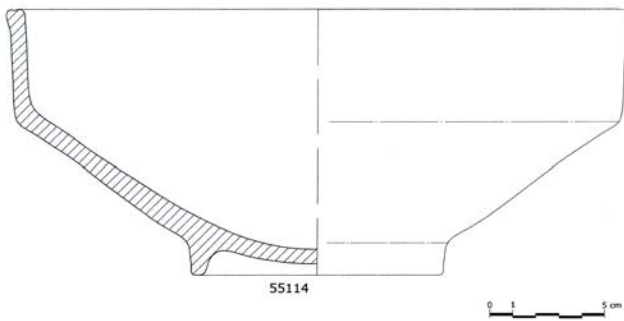
Fig 7: Fragment N.I. 55114 - Section obtained from manual survey.

Fig. 8: The reconstructed shape.

solid of revolution, it was possible to start from the section obtained from the relief executed by archaeologists with the traditional technique of the comb[24].

Section, after flat vectorialization, was compared with other sections of the fragment extracted from the mesh.

To derive the section from the mesh is was used a CAD program, considered essential for an optimal geometric control.

An horizontal plane was identified and three points belonging to the circumference of the edge of the fragment have been positioned on it.

Thanks to parallel planes several circular sections of the fragment have been identified and their centers allowed the positioning of the axis of revolution. The real objects, realized with a manual lathe, have a level of accuracy not too high, so the axis of revolution was placed choosing the position considered more acceptable to the generation of the surface.

The overlap of the hand-drawn section with that one obtained from the CAD model allowed to make some corrections, which are recognized to be minor.
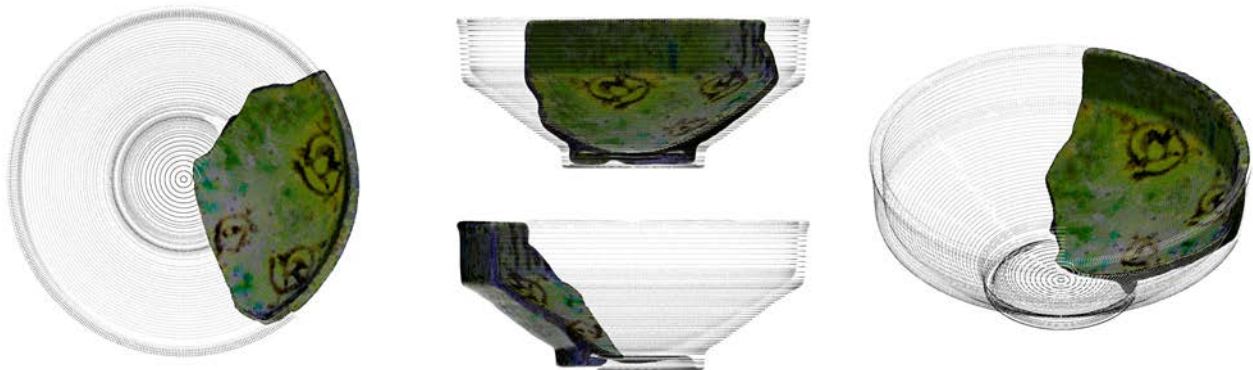
They have been generated, in this phase, the

Fig. 9: The original shape overlapped to the polygonal mesh obtained from the points cloud.

The phase of collimation, processing and optimization of polygon meshes was performed with MeshLab and Cloud Compare, both open-source programs.

The next phase has provided for the reconstruction of the original shape of the object in its entirety.

To get the original form the drawings conducted by archaeologists were essential. In the case of finding n. 55114, for example, being a

polygon model of the fragment and the solid model of the object in its original form.

It was preferred a solid model in order to make a correct boolean operation in the successive phase: the form of the fragment is subtracted from the model reconstructed, so that the reconstructed surface may become jammed with the fragment.

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[24] Courtesy of A. Salinas Archeological Museum of Palermo. Survay and drawing by Arch. M. A. Parlapiano.
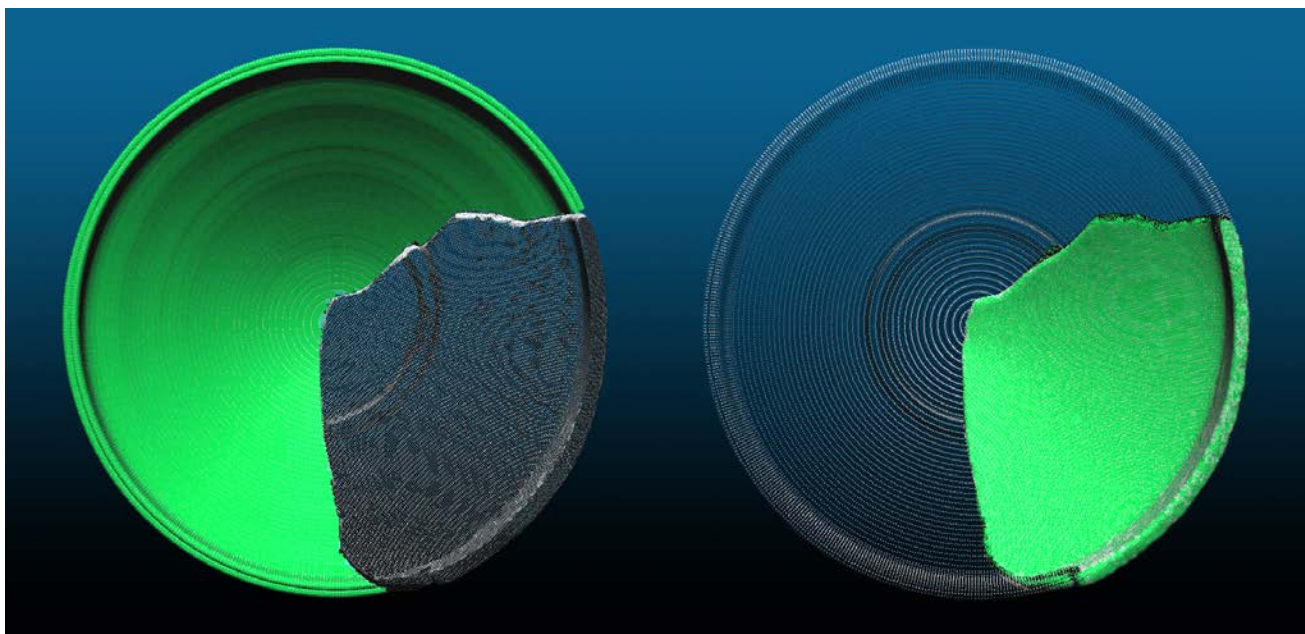
Fig. 10: On the left, the virtual reconstruction of missing part and, on the right, the polygonal model of the fragment.

The final model will be, therefore, formed by the combination of textured mesh of the fragment and the geometrized surface of the lost part.

4.3 Output systems for museal exhibition.

The development of digital models is not the final step. Their implementation is, in fact, one of the pieces that make up the mosaic of the fruition of archaeological finds.

It is necessary, therefore, in the work's pipeline, to determine which is the purpose of the digital modeling.

When we need just to obtain the visibility of the object is enough to reconstruct the fragment by processing a textured polygonal mesh.

The digital model of the single finds lends itself to many uses both on-site and online[25].

It can be assumed, in fact, a virtual archive of all those parts that, for various reasons, cannot be exposed, as in the case in which they are in phase of restoration or still object of study and cataloging. As often happens in our museums, in addition, there is not such a large exhibition space to accommodate the huge number of artefacts found in stores: the exhibition of digital models could solve the problem until the finds can not be physically exposed.
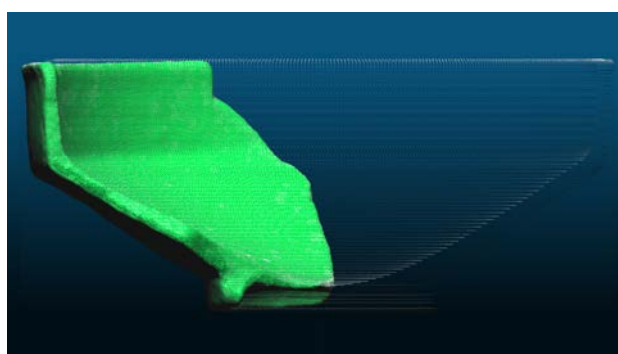

Fig. 11: View of the model of the fragment.

A digital archive, accessible through a simple touch screen, allow the visitor to look at models of artifacts not exposed.

The system can also be used also for the finds already exhibited, which may be viewed in 3D from different angles or with strong zoom factors, overcoming the limits of exposure in static museum display cases.

The model of the find, when possible, can be integrated with the conjectural reconstruction of the original form, which can be made visible or not by request of the user.

The method does not involve implications about the rules of the archaeological restoration, as if further studies would put in doubt the form or the decoration, the virtual reconstruction can be updated at any time.

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[25] About virtual museums and on line services see: (Toschi, Orlandini, Sbardella, & Simonetta, 2013).
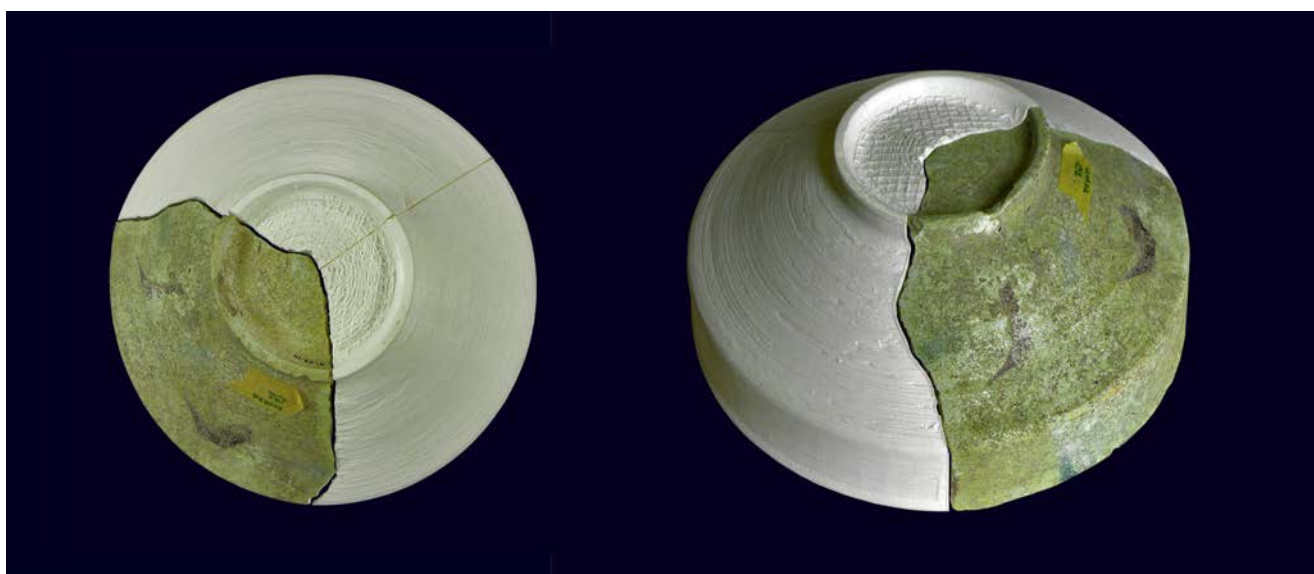
Fig. 12: The PLA model.

Fig. 13: Check of the fragment insertion in the PLA model.

4.4 Rapid Prototyping and reconstruction criteria.

Another possibility for the output of the digital model is given by Rapid Prototyping[26].

The digital model of the missing portion is manufactured using a process of Fused Deposition Modeling (FDM) by stratification of polylactic acid filaments (PLA). The choice was determined by various factors: first of all, also in this phase, the realization of the model is realized with low cost machines and with low cost

manufacturing process; the material is inert and does not create problems of chemical interaction with the exhibits; it can be polished to improve the finish; finally, it can be covered with layers of plaster or similar material which, when polished, offer aesthetic excellent results, fully compatible with the aims of the exhibition of an archaeological museum.

The realization of physical models is proposed as an exhibit system alternative to those currently in use. Today, to suggest the reconstruction, in some cases, some drawings of hypothetical reconstruction has provided, in others cases

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[26] About phisycal modeling see: (Pignataro, 2013).

fragments are placed in physical reconstructions realized by the restoration laboratories.

The idea is to propose a new exhibition system in which the fragment is placed in the PLA model allowing the observer to see contextually physical reconstruction.

Fig. 14: PLA Model with stucco, polished and colored.

the fragment and it is not necessary the use of glues or putties. This allows an immediate access to the fragment that may be removed at any time and studied in its entirety.

About the exhibition aspects the yield of the finished material is an aspect that cannot be overlooked.

The product in PLA, in fact, even if it may be finished with accuracy, being constituted by superimposition of layers, doesn't present a continuous surface: so the contrast with the aspect of the artifacts would be totally unacceptable. It was discarded from the beginning the idea of using colored filaments, as the color range available provides too little opportunity and shades are often too bright to be placed near the subtle colors of the exhibits.

It was preferred, therefore, after careful

Fig. 15: The final insertion of pottery fragment in the PLA model.

The current techniques for restoration, in fact, subject of perennial debate, provide a reconstruction of the object, in its original form, with the insertion of the fragments which, at the end of restoration, are irremovable. The result, often excellent in terms of exhibition, suggests some questions: one is relative to accessibility to the fracture of the fragment, in order to obtain precious information about the original material[27].

In the proposed system, the PLA model, thanks to some little devices, acts as a support to

thought, to postpone the selection of chromatic shades to a later stage.

Above the polymeric material it has passed a very thin layer of plaster based on cement and chalk, to make the surface smooth, and, after a thorough smoothing with very fine sandpaper, we moved to the choice of color.

The finishing material leaves much room for color choices, as it allows the preparation of tempera or acrylic paints.

In this case it was used an acrylic color whose hue was achieved in the Restoration Laboratory of the Salinas Museum, making sure to look for the one considered most suitable to exhibit.

It should be pointed out that the proposed system can not be used indiscriminately, as it has

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[27] Exactly for this reason often a small deviation of the reconstructed part is made, at the expense, however, of the continuity of the surfaces.

Fig. 16: The model optimized for 3D printing and the PLA model.

some limitations: in some cases, for example, fragments cannot be placed precisely in reconstructive model as the information that you have do not allow it.

The system opens, however, interesting scenarios for both the study of archaeological finds, and for the proposal of new exhibition systems[28].

5. 3D reconstruction: from photo capture to fused Filament Fabrication printing workflow.

Structure From Motion (SFM) is a Close Range digital photogrammetry type technique.

It became popular in 2008 through Bundler Open Source released by Noah Snavely under the GNU General Public, after 2006 SIGGRAPH research work of Steven M. Seitz and Richard Szeliski.

In 2010, Yasutaka Furukawa and Jean Ponce released Patch-based Multi-view Stereo Software[29] (PMVS2) accordingly Clustering Views for Multi-view Stereo (CMVS) by Yasutaka Furukawa, realizing the basic core of an open source for Structure From Motion pipeline. Then the Open Street Map-Bundler (OSM-Bundler) suite and the Python Photogrammetric tool (PPT), by Pierre Moulon and Arc-Team, added features and facilities to the workflow.

Work pipeline starts from generating a sparse cloud point from Bundler, then redefined to Dense Cloud point through PMVS2 and CMVS. We started from two sets by 64 or 32 shots, taking care to frame full subject in front and back poses. Picture were shooted by Canon EOS 400D DSLR equipped with CMOS APS-C (24x36mm) 10.1 megapixels (3888x2592p) and EFS 18-55mm lens using when possible F/18 focal length, opting for a slight underexposure. Sparse cloud Point was

accomplished by restrained Bundler's algorithm VLFEAT (GPL 2.0).

PMVS2 merged all clouds point togheter and removed all non static object from scene. Finally we obtained two clouds by 782,201 and 598,594 points each. Point clouds generated by bundler were encapsuled in Polygon File Format (PLY) developed by Greg Turk of Stanford University, who associates with the point even the color information.

Points Clouds were cleaned by not related elements, and collimated by Cloud Compare, an open source software made by Telecom Paris Tech and R&D pepartment of Electricity of France, developed by Daniel Girardeau-Montau in 2003[30].

Collimation was carried out through homologous points identification in at least fifteen different area, thanks also to references inserted in scene for that purpose. Operation has also contributed to resizing of clouds point between them, making rotoranslation and scaling to obtain a global system of space and dimension. Then Filter noise decimation option allowed to obtain one cloud of 173 351 points. We used MeshLab for surface generation, an open source software developed since 2005 by Paul Cignoni at CNR-ISTI and supported by 3D-COFORM consortium.

MeshLab has been used to correct normal orientation, and generate mesh surface by Poisson algorithm, setting octree depth at 10, and node of samples to 1.0. This phase generated a polygonal mesh of 346,696 triangular faces. After the Poisson algorithm application the model ready for 3D printing was generated.

We moved color information from cloud points to mesh surface by space optimized interpolation from "Trivial Per-Triangle" filter on Meshlab, generating 4096x4096 pixels triangulated texture. Finally the meshed model has been scaled through absolute measurements from the real object, using metric elements

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[28] Paragraph n. 4 is entirely w ritten by Fabrizio Avella.
[29] (Furukawa, & Ponce, (2010).

[30] (Girardeau-Montaut, 2006).

included in captured scene, and also relying on previous designs. Diameter determination was done by repeated approximations (about ten) from various point from the model, with the aid of the manual survey.

The new section was drawn by LibreCAD, then revolved to rotation solid by Blender, taking care to make triangulated mesh. Blender is a 3D modeling software developed since 1995 by Ton Roosendaal as commercial software, then turned open source since 2002, driven by the Blender Foundation. LibreCAD is a 2D CAD open source software, QT-based and compatible with DXF file format.

Once model was complete, fragment was overlapped to the solid rotation model. Offset-edges Blender's command was used to easy stick models together, then we proceeded to boolean subtraction, restoration of normal and solid rebuilding.

No information has been added from texture colors, being useless for FFF 3D printing purpose. Printed objects's size made mandatory split model into two pieces, to fit printer's plate. This has been achieved through Blender's knife tool, followed by mesh reconstruction by filling hole tool, verifying normal's direction related to the surfaces of the object, and watertight's respect to closed areas of the volume. Files were converted to Standard Triangulation Language (STL), by transforming solid's volume into triangulated mesh, verifing manifold's geometry.

We then proceeded to the model slicing and to the G-Code conversion through slic3r. G-Code was defined by Massachusetts Institute of Technology (MIT) in the fifties, and then ratified in February 1980 as a RS-274-D for CNC tool paths machines and now used by most of the 3D printer.

Slic3r, by Alessandro Ranellucci, was used for tool paths generation by 0.35 mm layers, for building contact surface extension of printing plate, and support arms for projection. We set a filling volume (infill) of 20% with square pattern of 45 degrees. The print was made in PLA, by a modified Wasp Power Wasp EVO with heated printing plate. When the print process was over, support arms were removed by hand, using sandpaper and calipers, and then the mdel was ready for the finishing phases described before[31].

6. The Augmented Reality system

As for the display in Augmented Reality, an approach based on markers has been chosen, using barcode recognized by the software (Quick Response Codes, QR-Code) within a video stream from reality, from which, in real time, it is reconstructed the virtual object oriented with respect to the real scene.

For the realization of the graphics engine, there is leaning to a open source framework based on Processing, nyARToolKit, and arsenic. Processing is a programming language with multi-platform Integrated Development Environment (IDE) born to be used in electronic arts, visual design and interactive installations. Released under the GNU General Public License in 2001 by Casey Rears and Benjamin Fry of MIT Media Lab, has a syntax similar to C and Java, adopting an object-oriented programming.

NyARtoolKit is a conversion in Java language of ARToolKit, a cross-platform library for the management of overlapping three-dimensional virtual objects on real marker. It supports multiple input devices and various methods of video capture which applies different patterns of camera tracking and recognition of planar patterns. It allows the customization of the patterns of markers and the recognition of multiple objects simultaneously. NyARToolKit is developed by Hirokazu Kato with the support of the HIT Lab (Human Interface Technology Laboratory) of the University of Washington and is a GPL 3.0 for non-commercial use.

Arsenic is one sketchbook2 for processing created by Massimo Avvisati within Codemotion3 Kids for the use of libraries nyARToolKit for augmented reality, also released under GPL 3.0. The sketch series allows detection of tags and import of three-dimensional models in obj format, with its texture format mtl.

The latter solution of integrated visualization on AR, performed on a find sample, is currently only a hypothesis, since the exhibition of Islamic ceramics is currently under reorganization[32].

7. The display system for virtual exhibition

The scansion of finds and the three-dimensional models of the missing portions allow

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31 Paragraph n. 5 is entirely written by Demetrio Siragusa.

32 Paragraph n. 6 is entirely written by Demetrio Siragusa.

to develop a system of virtual exhibition, which suggests an interactive use.

To allow the user's access to three-dimensional models an User Interface that makes navigation very simple has thought in order to provide a satisfying User Experience.

The page is structured thanks to a header with reference to the section of exhibition, on the

The file containing the exhibits is made with a video game engine, suitable to meet different needs: by its nature, in fact, handles very easily textured polygonal surfaces, especially if properly optimized through operations of retopology, easily allow operations necessary to make visible and invisible parts of the models, and allows to process a simple interface for managing them.
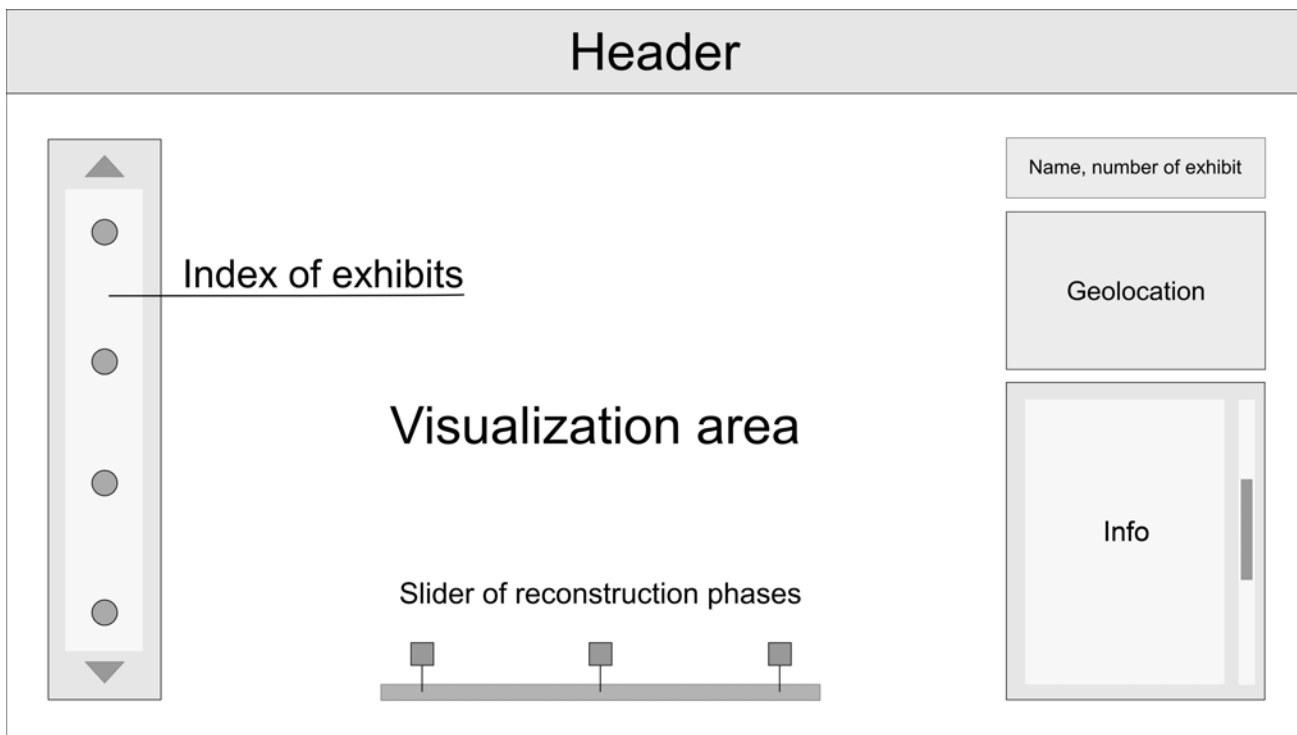

Fig. 17: User Interface scheme**.**

recommendation of the Museum, a panel with links to the database of the exhibits, a display area and a function panel in which to viusualize the information on the piece displayed. It is also added a slider that allows the different stages of display, from the finding on a three-dimensional virtual reconstruction.

The panel of the link allows you to open the single file in which the exhibits are assembled according to the criteria suggested by the instructions of the archaeologists. Every group of files must be changed at any time by adding models as you proceed to the survey and the 3D model of new find.

One of the main aspects which has to be considered in a visual system is the simplicity of use. It should be fit not only for scholars but also for non-expert users and it should let them have a pleasant experience. The functions necessary for the interactive use are of various kinds. The choice of the fragment let appear simultaneously the three-dimensional model in the display area and, in the toolbar functions, the description and its inventory number, the geolocation and the text box of information with an accurate description of the find.
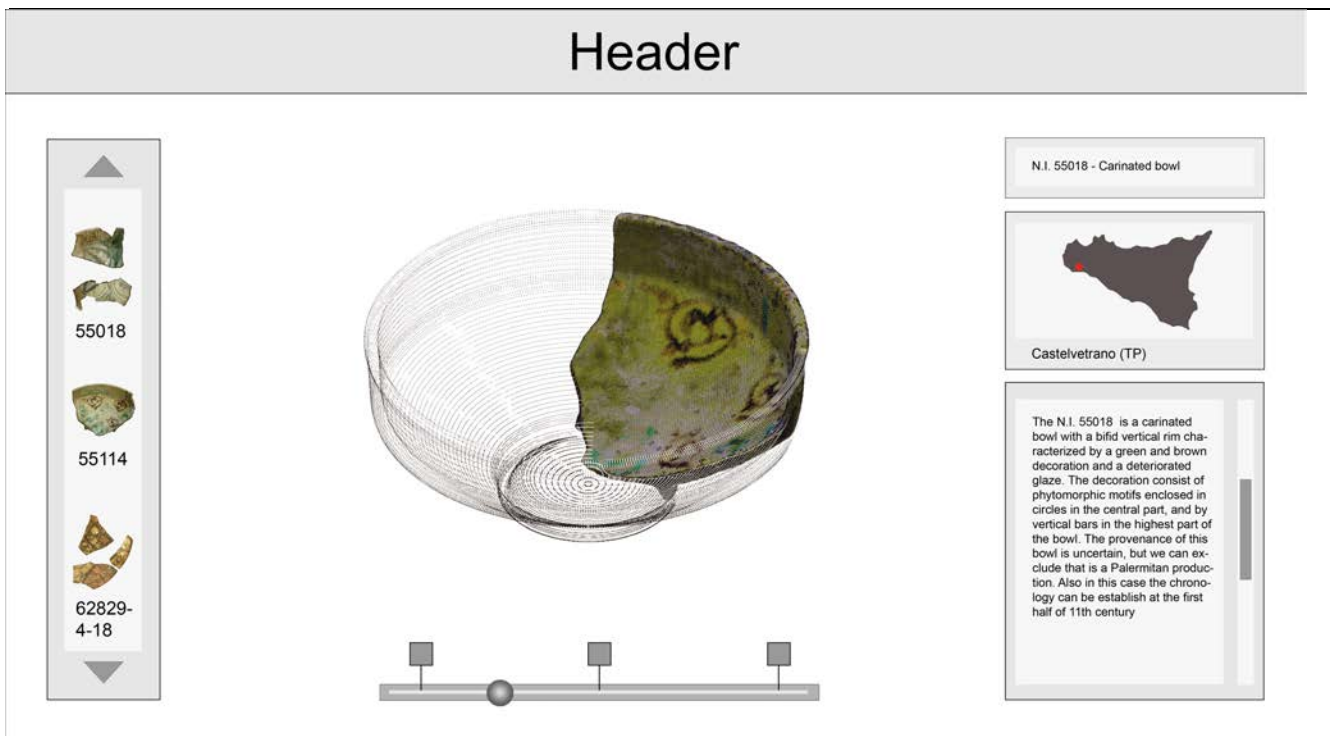
Fig. 18: User Interface scheme**.**

Fig. 19: The effect of the slider in 3D model visualization**.**

The display of the object's provides a vertical axis fixed orbit and a zoom bonded to avoid "enter" into the mesh or to get too far away. The slider below the display area allows to bring up gradually the virtual reconstruction of the missing portion, and, where the finds allow a reliable reconstruction, can be displayed the reconfiguration of the original decoration.

The effect is achieved due to the overlap of various polygonal models, with different levels of information: the polygon mesh of the find obtained by scanning with RGB data, the polygon mesh of the conjectural reconstruction of the form in its entirety, and, where possible, textured polygonal mesh with the decoration in its entirety[33].

Conclusions

The museum exhibition uses, increasingly, technological solutions for the archaeological heritage fruition. In a time when the difficulty of finding resources for the enhancement of cultural heritage is a major problem the development of low cost systems can be one of the possible paths to solve the problem.

The proposed system presents significant potential aspects for the exploitation and promoting knowledge of cultural heritage.

The benefits apply to both scholars that users of the museum. The former have a system that allows at any time accessibility to fragment because the filling is immediately removable; this is an operation impossible whit traditional restoration filling, reversible but modelled with adherence to the fragment. The users of the museum have a double advantage: one, of undeniable value, it is to see the fragment

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[33] Paragraph n. 7 is entirely written by Fabrizio Avella.

integrated in its physical reconfiguration, the other one is related to a virtual fruition which can allow, in addition to the visibility of the reconstruction model, a system of access to information that can be inserted in a very wide network of open data.

The reduction of costs for the realization of an integrated system of fruition is finally a further aspect which invites to continue the path just started.

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