

Photogrammetry of the Microcosms:

Investigating the landscape of single stones to create bases of knowledge.

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Abstract: The quite new group of photogrammetry software has highlighted how the use of Structure from Motion procedures can be a well working solution on archaeological, architectonic, urban and Cultural Heritage subjects. All the main experiences and case studies around are mainly aimed to buildings, urban parts or objects, but being based on photography this kind of software can be applied to almost any subject. The use of photogrammetric digital solutions can be easily exploited to study the sampling of small part of stone out of a complete architecture, creating detailed landscape out of a detail and allowing a specific reading of the content of this small world. The main task can be the one of reading specific alterations, or particular issues in the manufacture of the piece. The main technical troubles are linked managing this small parts and editing them to create really usable elements and bringing them in an efficient workflow. In this study the base of the analysis about procedures and data treatment will be based on a set of samples coming from the collaboration between the Departments of Chemical and Geological Sciences from Cagliari and the one of Architecture from Florence on a large group of Romanesque churches in Sardinia; some sampling from the rupestrian churches and settlements in Cappadocia (operated during a research project by the Departments of Architecture in Florence and the Cultural Heritage one from Tuscia), some sampling from major monuments in Florence (operated as personal research). The presentation will be aimed to describe and discuss the shooting solutions, the software procedures and the post processing on data compression and final treatment. This interesting and non-invasive method will be analysed in detailed and all its main features will be described on the base of practical examples.

Keywords: Photogrammetry, Sardinia, Data treatment, Structure from Motion

Introduction

Starting from the 2012, the Department of "Scienze della Terra" from the University of Cagliari, has developed a partnership in collaboration with the C.N.R. in Cagliari and the "Dipartimento di Architettura" from the University of Florence. This group started working on a project financed by the regional government of Sardinia ("Regione Autonoma della Sardegna"). The project is called: "The Romanesque and the territory. Construction materials of the "Sardegna giudicale": new approaches for the valorization, protection and restoration". The aim is to operate a complete documentation and support a correct reading of the system of Romanesque churches all over the Island. The Romanesque churches are a significant territorial architectural element in Sardinia, and there, they assume very specific characteristics, reinterpreting a sort of European language of the Christian architecture using local materials and experiencing original or differentiation in the solution for parts or in the whole spatial organism. Often these buildings present a

mixture of elements with the use of the local geomaterials, with the evident effort to replace the elements of the continental language, often reusing spolia elements coming from previous structures from the Roman and Punic ages. All is done, obviously with the prevalent use of local stones and re-reading the structure of the church according to the particular condition of each settlement. This project from the partnership guided by the unit from Cagliari is articulated around four main research sectors: the comprehension of this Architecture language in its specific Mediterranean context; the reading of the single Building using digital survey technologies; the multidisciplinary approach to the Arts applied and related to each church; and the comprehension of the materials and building techniques used in these churches. The detailed group of participants to this research project is the following: *Dipartimento di Scienze Chimiche e Geologiche* (coordination, Petrographical analysis, sampling of the materials), University of Cagliari; *Dipartimento di Architettura*, University of Florence (Digital Survey based on 3D Laser Scanner and Photogrammetry. following data treatments); C.N.R.- IGAG (National Research Centre) Cagliari Unit (MSA analysis, XRD analysis); *Dipartimento di Studi Storici, Geografici e Artistici*, University of Cagliari (historical studies; archive searches; formal reading and interpretation).



Fig. 1 – The church of Santissima Trinità di Saccargia (Copyright: Giorgio Verdiani)

About the Romanesque Churches in Sardinia

Using the words from Giovanni Sanna:

The numerous Sardinian churches are small, simple and uncoloured except for the natural colours of the stone; the red of sandstone, the black of basalt and the white of limestone. The most beautiful churches are the medieval ones. After the year 1000 the need to spread the Catholic religion throughout Sardinia started the most extraordinary architectural development in the history of this

ancient island. Architects, stone masons and decorators were sent to the island by the pope or recruited by Sardinian judges to build churches. A group of French monks, the Vittorini from Marseilles, built a chain of churches which represent the clearest evidence of the spread of the Catholic religion among the Sardinian people. These churches are monuments of the spirit, the stones of the faith. In the following 200 years, nearly 70 churches were built all over the Island. Most of them were in the countryside far from the urban centres.

And taking the words from the "itineraromanica.eu" website:

The isolation of a few medieval sacred buildings was sometimes motivated by the need to be set in a barycentric position over the ruled territory. Hence, this type exclusively applies to churches on which other sacred buildings were dependent, with their related inhabited centres. A few sacred buildings standing in an isolated position, for example on top of a rise, allowing a special visual control over a wide portion of territory, assumed in the Middle Ages a strategic-military function, too: in such cases, the occurrence of a bell tower is often pre-existing compared to the church, suggesting a possible use as watching/signalling tower. With special reference to monastic churches, on the contrary, the isolation from inhabited centres was a strategic choice explained by the need to ensure a defence against enemies and the marshy waters of the plain, but also by the will to exploit at the best the natural resources (stones, wood, water) offered by their wide dominions: the most privileged position was, then, halfway up the mountainside.

All these considerations fully apply to the Sardinian environment, with the system of the Romanesque churches fitting to these conditions.



Fig. 2 – The church of San Saturnino in Cagliari (Copyright: Giorgio Verdiani)

The digital survey

The first need of this research was the creating a basic dataset for referring all the gathered information coming from the various units involved. For this reason an extended and complete survey of a meaningful set of Romanesque churches was operated. The selection of churches was done considering the architectural characterization, the specific building techniques, and most of all a balance between the type of geomaterials in use and the geographic position. The digital survey of the system of the churches was operated using three different solutions: 3D laser scanner survey, photogrammetry of small elements and artworks, photogrammetry of construction material samples. The case of the analysis presented here belongs to the second and third solution.



Fig. 3 – The Laser Scanner at work (Copyright: Giorgio Verdiani)

Photogrammetry of small elements and artworks

In every church there is a series of elements usable to understand the story and the characteristics of this area: elements like capitols, decorations, sculptures, friezes and statues are unique elements, and it can be often useful to have a good 3D model of these parts. The methodology used has been the photogrammetric survey of these elements. This solution allows the production of data with a superior level of detail in front of the one offered by the 3D laser scanner and it can speed up the overall survey operation. This happens because in this way the detailed survey results are separated from the general one, which can be optimized for the architectural scale. The photogrammetric survey was done using two professional digital SLR cameras, a Nikon D700, with a resolution of 10.3 Megapixel and a Nikon D800e, with a resolution of 36.3 Megapixel, both the cameras have a full frame size sensor and were equipped with a Micro Nikkor MF 55mm F2.8 lens and a Micro Nikkor AF 60m F2.8 lens, these lenses are famous for the quality and the very sharp

and accurate image they create. These lenses are extremely versatile to take picture of details because they have a good capacity to reach a minimal distance with the subject. They also have a significant feature: their focal length allows a good depth of field stopping down from F8 and has a quite pronounced perspective (similar to the one perceived by the human eye) and this helps the photogrammetric software (the presence of a high depth of field in some photos generate some problems in the alignment process of the software and in a subsequent point detecting). Because of the fact that these lenses were originally designed for macro photography, they allow to stop down to F32 or even to F45 with an increase in the depth of field, generating a more extended number of usable pixels in the photogrammetric process. For every shot it is necessary the use of a solid and stable tripod: it allows a more rational and practical use of all the features described above. The kind of tripod used for these surveys has a double rail macro head: it allows an accurate moving and precise positioning of the camera, and useful feature for macro and close range photography. Finally it is necessary the use of a remote control: this tool removes any risk of shaking blur and complete the set of hardware for the photogrammetric shooting. Agisoft Photoscan is the software used for all the photogrammetric operations. It starts with the classic process of alignment, then it allow to go forward in the dense cloud generation, mesh generation, texture generation and, in the end, model scaling according to the data of the 3D laser scanner survey.

Photogrammetry: instruments and procedures

In each church it was operated a specific survey of some meaningful surface sampling, because the investigation about the geomaterials has a great importance in this research. It is necessary a selection of the most interesting points on the wall, and it is required the experience of the geologist, aimed to find clear decay phenomena and relevant alterations. The concept of this process it is the possibility to “capture” a high detailed sample of the stone surface without damaging the original wall. Obviously it is possible to think about a monitoring of the part of interest, in fact the high level of detail of the sample gives the possibility to check and verify very minimal difference between two models. It can to evaluate an accurate check of the on going decay of the surface with the simply repetition of the sampling. There is the need to locate and identify the sample at the moment of the survey with the use of specifically created masks, made to define clear and easily measurable areas, having at the same time markers along the border to help the identification of the original placing of the sample. The body of the mask is a square and have a cross carved hole in the centre, the middle of the cross is 49x49 millimetres in one set of masks, while in the other set it is 24x24 millimetres. It is a simple and fast way to frame the central area of the sample and to have some point of reference to help putting in scale the final model in Agisoft Photoscan. According with the characteristic of the sample and the “size” of the decay/alteration/phenomenon to be surveyed it was chosen the smaller or the larger cross mask and almost all the pictures with the larger cross have been taken framing the whole mask, while in the use of the smaller cross masks the framing was only around the cross itself. The size of the pixel in the photogrammetry made with the Nikon D800e camera when using the large cross masks was around 0.017 millimetres (with a certain range of variation) in the frontal shots. According to the richness of the masonry, in every church there was the choice of a number of samples from 4 to 10,.The size of the mask is very small to use the data from the 3D laser scanner survey to put the masks in scale , so each mask was numbered

and measured again after the survey process to reduce to the minimum the possibility of an alteration in size of the model and, in the end, a digital caliper was used for all these measurements. All the data were organized in records with the description of the sample (location, material, a picture with the whole target applied on the wall, a sequence of sections according to the two main axis of the target) for each record an Adobe Acrobat PDF 3D or other multimedia solution is associated to allow the viewing of the generated 3D model, in this way every model developed out of these samples are catalogued. Right now a first archive is available to the research group: a database with the photogrammetric survey of 78 samples of the various churches and locations. The way to generate a 3D model of the samples using SfM (Structure from Motion) software is simple and cheap. These procedures are now in a great moment, based on very well working software, their main vantages are: the good exploiting of the digital camera features, interesting perspective of development, well working freeware (or with an "academic" low price) software tools, a quite short workflow for producing usable 3D textured models. The result is a sort of "return" in the Cultural Heritage subjects of the photogrammetry techniques, with a more than ever "immediate" and "easy to use" logic. But the fact is that this is a low cost procedure and is thought to work with standard photographic equipment. Some online solutions, like the Autodesk 123D App website, offers the possibility to produce a model virtually but also physically, selling 3D print-on-demand physical copies of the model generated from the uploaded pictures. The standard process necessary to produce a 3D model through a set of pictures consists in a photographic survey of the object (from the building to the small element, like a sculpture), made with a good illumination and a subsequent software operation, with a final generation of a textured 3D model of the object. The development of these processing was quite long through time, but it has reached a significant acceleration in the last five years with the production of important and well working software solutions like Agisoft Photoscan and free service package like Autodesk 123D Catch, Microsoft Photosynth and freeware programs like Visual SfM, just to name the more popular. There are numerous case studies about Cultural Heritage surveyed using SfM solutions, and this is due to the simple approach of the software solution and the very portable set of tools needed to work in this way. An important fact of this processing is that a lot of the possible accuracy and the whole quality of the final result depend on the quality of the shooting: not completely focused photos, micro-blurred images and lighting conditions, can reduce or even invalidate the possibility in obtaining a good quality model. So any high quality model starts, in this case, from a high quality set of pictures. It is possible to consider this solution as a very powerful tool, balanced between traditional and innovative features and available for multiple purposes and needs but with the option to be efficiently inserted in the general workflow of any research about Cultural Heritage subjects.

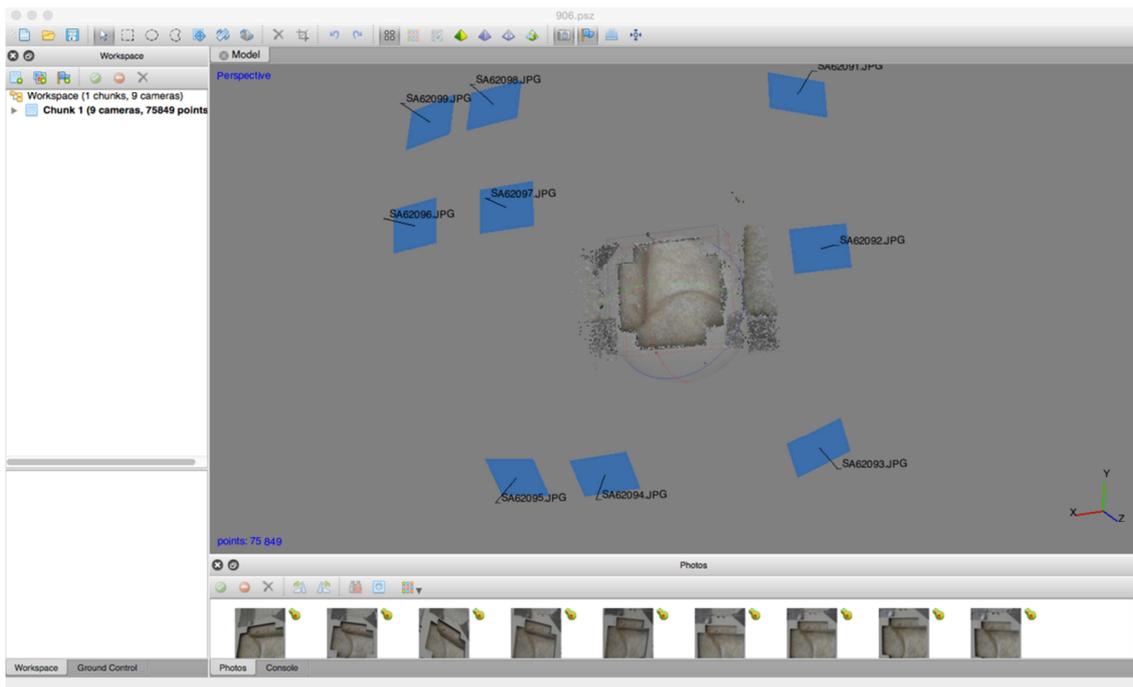


Fig. 4 – Agisoft Photoscan. The calibration of the photos

The generation of the 3D surface

The first step of this process was the generation of a 3D model with a high level of polygons (commonly named “high-poly mesh”) to describe every possible detail of the sample. The process was made using Agisoft Photoscan and the workflow was the typical one for this kind of software: a first step based on automatic calibration and positioning of the photos in the 3D space, and the consequent generation of a pointcloud with chromatic features of the object. After these first couple of operations it was possible to calculate the high-poly mesh, this first resulting model coming out from this processing was commonly made of a set of polygons from seven to nine millions of faces (with the set of pictures taken with the Nikon D700) or from twelve to eighteen millions of faces (with the set of pictures taken with the Nikon D800E). Holes, complexity in shape and articulation of the surface can influence the final result. This result has some critical factors and it was not directly usable for common use not for multimedia because of its “weight”, otherwise it represents the first starting point of the model processing. The first step of post processing was the mesh editing, used to resolve all the difficulties in managing the surface with operation of filling the holes and correcting small and medium mistakes produced by the automatic surface creation, like for example the problem of the overlapping of the polygons. It’s very difficult and hard the process of identification an selection of the holes in a high-poly mesh and It’s possible to have some risk in making improper corrections on the surface, so It’s necessary a great attention for the operations of this phase. The operation of texturing involves a similar condition, because it’s practically impossible to manage an UV map with a very high number of faces. A high-poly model has problems not only with the view and navigation cations, but also any editing with most of the commercial hardware: it makes necessary to operate using high performance workstations. In the end, it is worth to be said that, every multimedia system supports the use of only “light” model, because the web application (for example the applications developed using Unity) doesn’t run high-poly models, being created for a fast data transmission and to be used with basic performance hardware like

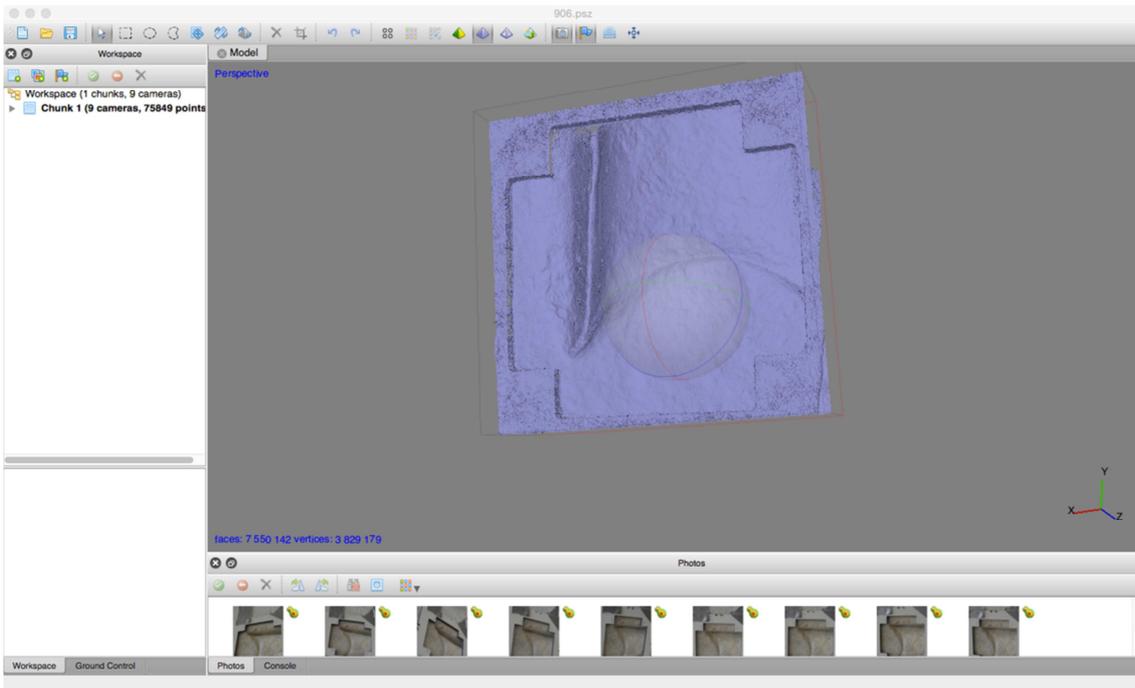


Fig. 5 – Agisoft Photoscan. The generation of the mesh

home computers, tablets and other personal devices. So it is necessary the production of an optimized 3D model, with the generation of a geometric surface made by a reduced number of polygons (commonly named “low-poly mesh”), with a well-done normal map and a chromatic texture derived from the high-poly mesh to enhance the visual appearance of the final result.

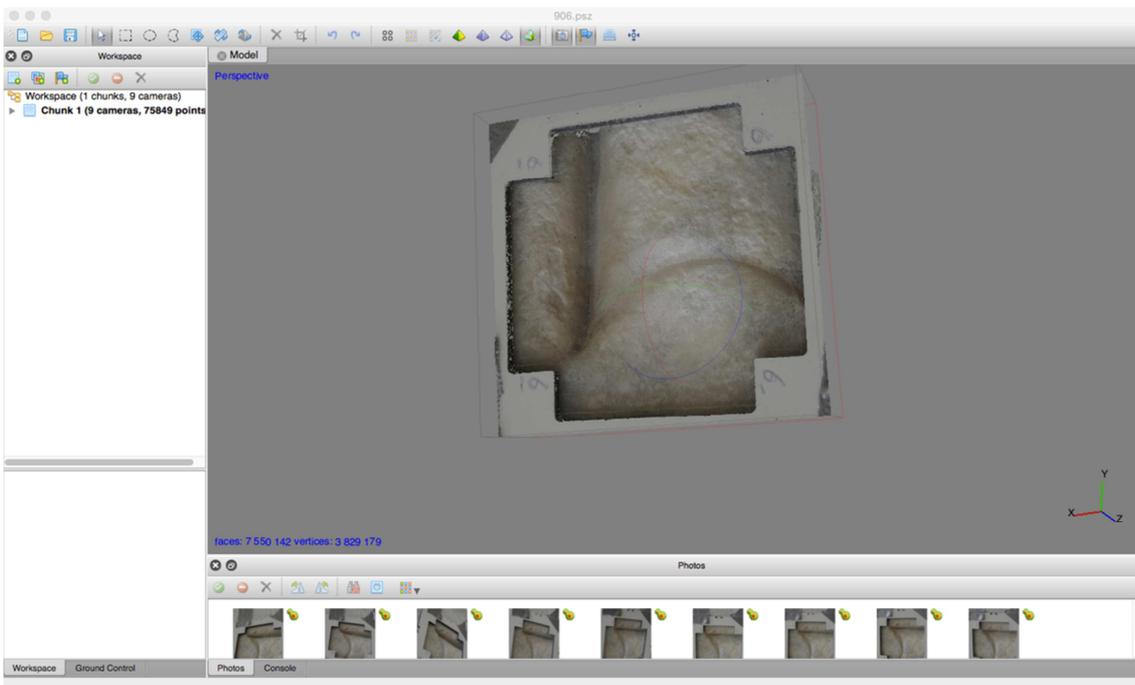


Fig.6– Agisoft Photoscan. The 3D surface textured

The decimation process can be made within the Agisoft Photoscan itself or even with other surface editing software. The resulting surface is a low-poly mesh, but it is necessary to do some extra editing process to fill some minor holes and to filter some residual noise in the mesh. The step after this process is the generation of an UV map, necessary for the subsequent operations of baking and texturing aimed to produce the final model for multimedia usage. The UV map is a bijective correspondence associating the coordinates X, Y, Z of the mesh to the UV coordinates of an image. After the baking process, the UV map of the low-poly objects can receive the normal map, the texturing and even other kind of maps coming from the high-poly mesh. The low-poly mesh, after the application of these textures, will show the geometrical characteristic of a high-poly model, with a virtual increase of the numbers of polygons and a meaningful visual enhancement. If an external software is used to reduce the complexity of the surface, for the final texturing process it is necessary to re-import the low-poly mesh into Agisoft Photoscan. In fact, the edited result will be positioned in the same place of the original high-poly model, then the software will automatically generate the chromatic texture of the object and the process will be completed. At the end of this process an optimized 3D model is made, it will be usable for multimedia solutions. The new model is “lightweight” and fully compliant for exporting in one of the many possible/needed digital formats, and can be easily imported into other software to complete the preparation of the multimedia product. The high-poly model remains and it is usable as a higher quality documentation of the object or for specific analysis needs or for further studies/uses. It can be even used in the future to update the multimedia product in itself if there will be the option to use more complex models in the online presentations.



Fig. 7 – Low poly 3D models with the application of the normal map and the chromatic texture

The qualify analysis

It is necessary to verify the metric and geometric result of the 3D models generated in Agisoft Photoscan, because a wrong calibration of the photos can create some deformations and alterations and because an excessive simplification adopted to reduce the weight of the models can cause improper reduction in the quality of the final model. Last but not least the consolidation of a smart procedure about the stone samples is something to take into account for the following stages of the general project. It is foreseen to go back on certain meaningful samples and take again the photogrammetric survey. This will be done to check any possible changes in the surface and have a very innovative approach to decay monitoring. One way to control these problems and approach to this need is the use of a software like Raindrop Geomagic Qualify, specialized in checking and verifying (and creating reports) from similar models. With its procedures it is possible to analyse the deviation between two overlapping surfaces. The first step, to produce a valid qualify operation, is to align the two surfaces of the samples with the use of homologous points manually and automatically detected over the surfaces. With the use of these points the software can produce a rototranslation of the first surface on the other. After the two elements has been aligned it is possible to apply the qualify of the deviation between the two surfaces. This kind of analysis has been made to check the same model on various samples and most of the maximum deviation was minimal. The process was organized in this way: 1) Definition of a set of samples with different surface characteristics. 2) Production of the surface starting from the same pictures and same alignment from Agisoft Photoscan using different choices in the “mesh generation” procedure. 3) Simplification of the resulting surface using Agisoft Photoscan or Raindrop Geomagic. 4) Qualify of the resulting model. 5) Organization of the results.

Phase 1) Sample selection.

It were chosen a limited number of samples (4 elements) located in different areas of survey:

501: Surface detail of basalt stone from Santa Maria del Regno (Ardara, north-east Sardinia). This stone shows a vesicular macroporosity (typical of volcanic scoria or similar), from sub-millimetric to centimetric size, basically aligned according to the plans of volcanic flow (or degassing direction). The rock, even carved to create a phytomorphic figure, appears almost unaltered at chemical-physical level. On the surface is observed the presence of a patina with ocher colour, probably of anthropogenic origin, due to surface treatments performed in the historical period on which should be made more targeted analysis (i.e., X-Ray diffraction) for know the composition (i.e. calcium oxalate).



Fig. 8 – The 501 sample (Copyright: Giorgio Verdiani)

706: Surface detail of limestone from San Pietro di Sorres church (Borutta, North-West Sardinia). This stone shows various forms of biological species (i.e., lichens, algae, mold) that are implanted in the surface of the rock finding an ideal situation where develop, in the presence of nutrients provided by the stone, and more or less constant presence of moisture. These conditions are preferably in the basal façade areas of the monument, close to the ground and on surfaces exposed to the north.

604: Surface detail of basalt stone from Santissima Trinità di Saccargia church (Codrongianos, north-west Sardinia). The volcanic rock shows a great macroporosity, frequently with sub-centimetric size and sub-rounded pores, but the matrix of stone appears well welded and not shows chemical-physical alteration. In the middle of photo observed a xenolithic fragment-clast of rock with different origin and composition included into the basalt rock at the time of emplacement.



Fig. 9 – The 706 sample (Copyright: Giorgio Verdiani)



Fig. 10 – The 604 sample (Copyright: Giorgio Verdiani)

906: Surface detail of Roman marble stone from San Saturnino church (Cagliari). This element is a removed element from an ancient Roman building.



Fig. 11 – The 906 sample (Copyright: Giorgio Verdiani)

Phase 2) Production of the surfaces.

The first step is the generation of the hi-poly mesh. This operation is made with Agisoft Photoscan with a “no limits” of numbers of polygons process. The surfaces produced have a number of polygons from 6.000.000 to 16.000.000.

Phase 3) Simplification:

To compare the quality of the surfaces 2 decimated meshes were created they have 1.000.000 of faces each. This process is made proceeding in two different ways: using Agisoft Photoscan and Raindrop Geomagic. In the end there are two 3D models with the same number of polygons (1.000.000) but generated with two different decimation processes.

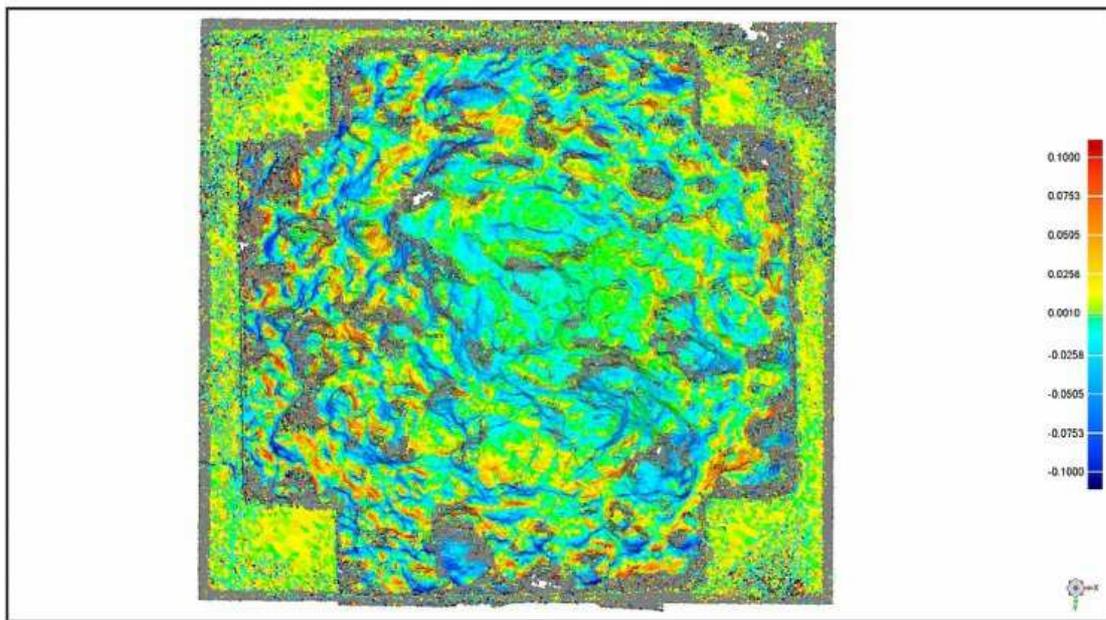


Fig. 12 – The qualify report of the sample 604

Phase 4) Qualify :

The next step is the qualify operation between the surfaces. The first comparison is between the hi-poly mesh and the decimated surfaces, then the second test is between the decimated models. All these comparisons give rise to a list of reports with the deviation value of the surfaces.

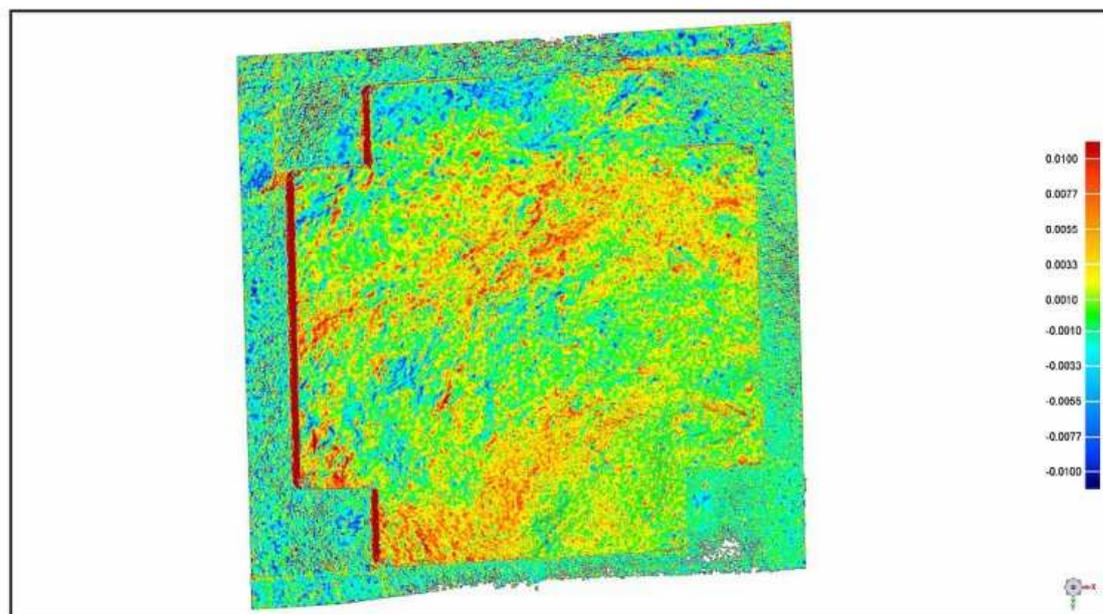


Fig. 13 – The qualify report of the sample 706

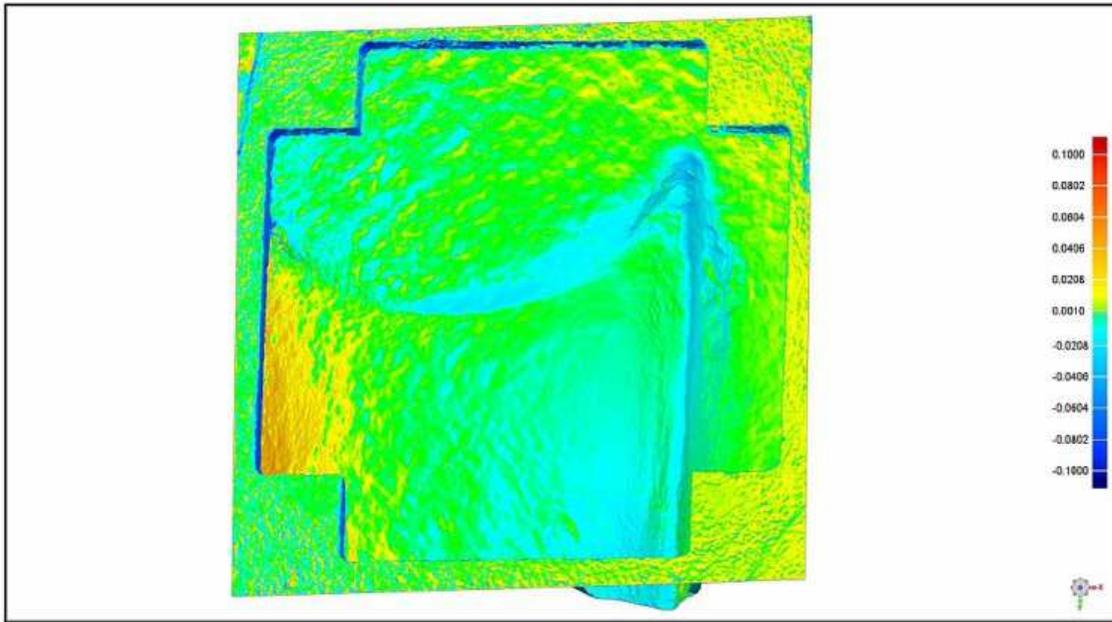


Fig. 14 – The qualify report of the sample 906

Phase 5) Consideration about the results.

The report was made with a range of deviation of 0.1 millimeters and a nominal subdivision of 0.001 millimetres. The qualify analysis between the hi-poly model and the decimated surfaces show a diffuse deviation about 0.02-0.03 millimetres, but in the qualify between decimated mesh this deviation decreases as far as 0.001 millimetres. In the analysis of the sample 501 the deviation between the model with 16.000.000 of polygons and the decimated surfaces is bigger, with 0.1 millimetres of offset. It's a 3d model with many holes and a with a noise diffused in all the area: probably the quality of the mesh affect this kind of analysis. It's interesting to note that the planar areas have a minor deviation than the articulated surfaces. Finally the maximum diffuse deviation of these samples is about 0.03 millimetres in a sample area of 49x49 millimetres, with a quantifiable error around the 6%.

Conclusions

The digital survey of this group of churches in Sardinia offers an interesting case study about the quality and the completeness of the photogrammetric and 3D laser scanner procedures, with a massive architectonic and structural survey where the use of 3D Laser Scanner and the detail survey of the small elements done with a photogrammetric procedure are integrated to exploit the best features of both the systems. The qualify analysis indicate that the deviation between the hipoly surfaces and the decimated mesh is quite reduced. Even the decimated model is a valid reference for further investigations and it is usable to create sections and drawings. In the future of this research it would be interesting, to understand the limit of the photogrammetric survey for this kind of elements. To operate such a comparison a survey made with high resolution and accuracy 3D laser scanner technologies should be needed. The data produced with a photogrammetric survey consent to produce a "light" but detailed 3D model of the sample, usable for multimedia archiving or dissemination purposes. In fact this type of model is ready to use with multimedia

publishing software, like, for example, Unity 3D. With this software it is possible to use the 3D model of the sample in an Internet browser creating a complete database of the small elements. The high-poly model is very interesting for the detailed and metric analysis of the samples. It is possible to use it to produce two-dimensional drawing, like section of the fragment, useful to understand the “state of health” of the sample with quick procedures, deferring a more accurate shape match at the main steps of the monitoring.

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