Different ways lead to different results?
Experiences on modern photogrammetric surveying on cultural heritage subjects

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Abstract: The aim of our research is to analyze three-dimensional models obtained by processing different survey data, to compare the specific workflows in terms of data gathering speed, performance and processing efficiency, errors and their mitigation methods in final digital models. The results will be achieved by a comparison between 3D digital models, generated by photogrammetry based on specific set of pictures, but the firsts from a Direct Survey Campaign (DSC) and the second from the Web: the variable of the research is the difference of the data underlying the processes. The DSC is executed in situ, in a short time, performed by a single operator with a tripod, so the resulting images are uniform for colouring and lighting. The Web Archive Survey Campaign (WASC) consists in a selection of web images, taking as a model an experience developed in October 2011 by the University of Washington, called “Building Rome in a Day”. The result is characterized by the many different shots collected: various photographic equipments, light conditions, exposure, web compression alterations, and many points of view. After a careful verification of data usability, the two groups of images are processed in dedicated softwares; then the calculation is finalized in a set of 3D-models with texture mapping. The final surface mesh will be subjected to comparative tests between the other models. The results obtained will contain the conclusions about the degree of reliability of WASC in front of the complete and exhaustive DSC methods, evaluating perceptual appearance, by image rendering processes, as well as through the reliability of the geometric return on errors observation. All the case studies will be aimed to Cultural Heritage subjects, analyzed in their specific contests and capable of giving a clear reference scenario of these important solutions for a simple, quick and functional digital survey.

Keywords: Photogrammetry, Survey, Comparison, Processing, Web Resources

The inspiration of this work is inspired by an University of Washington research, developed in October 2011, called “Building Rome in a Day” (fig. 1). In this work their research group started harvesting photos from the Web with the aim of building the 3D models of the most important monuments of Rome using photogrammetry techniques and then they repeat the method with other cities like Venice and Dubrovnik. Their final aim was to use touristic photos from all around the world to have the opportunity to explore and study three-dimensional shape of cities, monuments and significant Cultural Heritage sites. From this very interesting experience we start thinking about the final quality we can obtain from these models, and so we start to test our skills developing a project capable to give us good and usable results.
Choosing a good subject of study

An important statue in Florence
To initiate testing this method a good subject, a statue, with some specific characteristics was selected: first of all the location, in Florence (Italy), our city, a choice done not to be lazy, but because of the idea of having a near place, allowing to repeat shooting and surveys without the need of travels. Then other characteristics must be the importance and popularity among tourists to be sure to find web photos, a historical value, the accessibility during the early morning hours and to the entire surface of the subject, the height, because it must be not so tall compared to a man with just a reflex camera and a tripod and no other instruments or special permissions. In fact many of the most famous sculptures in Florence are very tall, about 3.0mt, and so it is very difficult to find out the right subject.

There were considerations made between the “Fontana del Bacchino” (fig. 2), located in the Boboli Gardens and the “Fontana del Porcellino” (fig. 3), in the Hall of the "New Market". Both of them are not very tall, are very popular among tourists and are interesting from an historical point of view.

As the Bacchino is located inside the Boboli Gardens, it can not be accessed during the early morning hours, when the lighting is best to reduce harsh tones on the subject. Moreover the fountain is really close to a wall, so it is impossible to surveying the back of the Bacchino.

After making these observations the "Fontana del Porcellino" in the Hall of the "New Market" was chosen because it is never close to public and it is accessible from 360°.

The “Fontana del Porcellino” in Florence

Historical notes about the fountain
The Fontana del Porcellino is one of the most popular statues in Florence and is located under the Hall of the "New Market", really close to Ponte Vecchio.

The name of the statue is not accurate, because it is not really a pig but a boar. The model comes from a roman copy of an Hellenistic marble that Pope Pio IV (1499-1565) gave to Cosimo I de’ Medici (1519-1574) during a meeting in 1560 in Rome. In 1612 Cosimo II de’ Medici (1590-1621) commissioned a bronze copy of the statue to Pietro Tacca (1577-1640) to place this copy at Palazzo Pitti. The wax model is from the 1620, while the bronze copy was executed in 1633, because of the continuous and urgent commissions sponsored by the Grand Duke, such as the fountains in Ss. Annunziata square and the monument called "I quattro mori" in Darsena Square, Livorno. In the following years as in 1640, Ferdinando II de’ Medici (1610-1670) chose to turn the statue into a fountain and placed it under the actual hall, but just on the adjacent side: this position was due to the function of providing water to the silk and wool merchants working under the hall. The fountain was moved in its actual position during the XVIII century with the need to facilitate traffic on the main road.

With the conversion of the statue in a fountain, Pietro Tacca designed and realized also a base for the boar, with the representation of the environment of the wild boar, swamps, turtles, reptiles and clams and with a small pool where falls the stream of water from the mouth of the statue.

The original roman copy is on display at the Bardini Museum.
Historical notes about Pietro Tacca (1577-1640)

Pietro Tacca was an Italian sculptor, in Tuscany, the most representative of the Baroque. From when it was only fifteen years old, he went to the Giambologna's Atelier and he became his best collaborator in 1601. At the death of the master, in 1608, he had the usufruct of his atelier and his home and only a year later became the sculptor for the Grand Duke. Tacca began by finishing Giambologna's equestrian bronze of Ferdinando de' Medici for SS. Annunziata Square in Florence, a project in which he had participated at every stage, from the terracotta models to the casting process in the fall of 1602 and the finishing by 1608.

Pietro Tacca's public works for the Medici include his masterpieces, the "I Quattro Mori", representing captured corsairs or Ottoman pirates (1620–24) at the foot of Baccio Bandinelli's statue of Ferdinando I de' Medici, intended to celebrate the above mentioned victories, in Darsena Square, Livorno. In 1612 he designed the statue of a boar for Ferdinando II de' Medici, now the "Fontana del Porcellino". Moreover he executed some other works previously designed by Giambologna, like the equestrian bronze of Philip III in 1616 and the one of Henry IV in 1613. His last public commission was the colossal equestrian bronze of Philip IV, after a design by Diego Velázquez (1599-1660). The daring stability of the statue was calculated by Galileo Galilei: the horse rears, and the entire weight of the sculpture balances on the two rear legs, a feat that had never been attempted in a figure on a heroic scale.

His son Ferdinando Tacca (1619-1686) assisted him in the atelier; the inventory in 1687 included sculptures doubtless by Pietro Tacca. After the death of Ferdinando the atelier was taken over by Giovanni Battista Foggini (1652-1725).

Data gathering: two different survey campaigns

The data selection used is based on two different initial survey campaigns: the first one, we call it Direct Survey Campaign (DSC) and the second one called Web Archive Survey Campaign (WASC).

The DSC (fig.4) is executed in situ and could be carried out by a single operator with a reflex camera and a tripod, so the resulting images are uniform for dimensions, type, lighting and colouring.

The WASC (fig.5) consist in a selection of web images characterized by many differences: various photographic equipment, dimensions, light conditions, exposure value, web compression alteration and different point of view.

The Direct Survey Campaign and the Web Archive Survey Campaign

As the time frame with the optimal light conditions, on the early morning was very brief, we chose to carry out the DSC survey with two reflex cameras, two tripods and two operators, shooting photographs surrounding the statue, obtaining a sensible reduction of the time required for photographs. A Nikon D700 plus a lens Sigma 12-24mm was used to shot more general photos of our subject, and a Nikon D7000 plus a lens Nikkor 16-85mm was used for the photos of the details of the statue. Were finalized 288 shots to cover the entire surface of the boar with special attention to facial details, to the fur and to the basement with natural environment.
To avoid the presence of too many tourists around the boar, but also the problems due to the direct daylight on it and the consequent reflection on the shiny surface of the boar’s nose, the campaign was carried out in the early hours of the morning, before the sun is too high.

For the WASC web touristic photos were taken from Flickr.com and Google.it, always respecting copyright laws selecting only photos without copyright, a total of 116 shots. A different point of view was taken in the search but it was obviously a tourist photo chosen to capture the front and the two side of the statue, so its posterior portions has negligible results.

Data processing

The same methodology on the two different survey campaigns

The processing of all the data acquired was done with a software of photogrammetry, for example Agisoft Photoscan 1.0.4.

At first the DSC data was processed by loading all the 288 photos on the software program and aligning all of them, building the sparse pointcloud with for a total of 1.400.000 points in High Quality Alignment. Then dense pointcloud was calculated by increasing the densification of the total points, obtaining a cloud of 64.000.000 points. After this the mesh was built to obtain a real 3D model of the Porcellino. Due to problems of our hardware and RAM limitations, the mesh was built on the sparse pointcloud, to avoid long calculation times and reduce possibility of software crashes. The mesh resulting from the sparse pointcloud has been calculated with a low decimation of the pointcloud and was very satisfactory having 770.000 triangles of very small dimensions. Finally, to complete the task the texture was calculated on the mesh (fig.6), obtaining the final textured model. The texture was also satisfactory having only a few problems in the area of the nose of the boar, where the surface was very shiny for the chafe of the hands of the tourists trying their luck.

Once finished with processing the DSC data, this method was applied on the photos chosen for the WASC by loading all the photos on the software and then started the alignment process. However there were not enough points to align all the photos, so the software aligned only 70 shots on the total of 116. The sparse pointcloud was made of only 32.000 points, much less than the DSC’s one. The process of calculating continued for the dense pointcloud that consisted of 4.000.000 points, exactly 60.000.000 points difference between this and the first one. The mesh is built on the basis of the sparse pointcloud to be coherent with the other example, obtaining a mesh of 42.000 triangles with many holes all over the surface, but with a good level of detail in the zones covered by the survey. Finally the texture on the 3D model was calculate arriving to the final result (fig.7).

After this phase of processing data, it can be noted that in both of the case studies, it was possible to calculate the final 3D model with texture. The differences in the processing have affected only the different time of calculation: while the model obtained by the DSC has required many time of processing, about two hours for the dense pointcloud, ten for the mesh and six for the texture, the model obtained by the WASC has required less time, in the order of two hours for the entire process.
Comparing the models
The final part of our work is aimed to obtain a scientific comparison between the meshes, so using a series of procedure that ended in a final schematic model describing the entity of the errors.

Scale the meshes using Agisoft Photoscan
Scaling the 3D models is a necessary operation to arrive at a final comparison between them. First was scaled the 3D model taken from the DSC, as it is the most complete and accurate one. To do this "direct scaling" operation it is necessary to take one measure during the survey campaign: always choosing a measure simply to found in the 3D model. In this case was used the width of the base of the statue. This measure, is a very "solid" reference, while it is supposed to have it constant in time, even in front of decay of the material. At the same time the size of the base is quite large to reduce to the minimum the possibility of size variation in front of the size of the pixel for both the models.
In Agisoft Photoscan two markers have been put on the points of the 3D model chose for the measurement and then has been added the measure taken before. After this, the same operations for scaling the 3D model derived from the WASC, have been done.

Align the meshes with Geomagic Studio
The second necessary procedure is to do the alignment of the meshes. In fact when you build the final models, as the photos come from a different survey campaigns also the reference system is different for both the models. Also in this case of the processing it was decided to start from the 3D model came from the DSC, aligning the referring system to it: in this way it is simple also to obtain default views as the sides view, front view and top or bottom views.
To align the meshes Geomagic Studio provide two instruments: the "manual alignment" and the "automatic alignment". The first procedure consist in finding four points common in the two 3D models, inserting markers on these points and then starting the alignment; while the second procedure is totally automatic for alignment and adjusting minor errors of scale, mainly due to the location of the marker on mesh surfaces with slight morphological differences. As it is not possible to control a totally automated process, it was decided to start with a "manual alignment", and only after a first alignment does the automated process begin. As a matter of fact, with only the "manual alignment" the software align the first marker perfectly and leaves the other three ones with some imperfections due to the different scale of the 3D models and the distance between points and the orthogonal plane that contains them. Only through the automatic process can one work around this problem: the software finds a solution scaling the second 3D model on the first one and probably in another very small rotation of the scaled model.

Compare the meshes with Geomagic Qualify
The final phase of our work consists in an analytic metrical comparison between the two models obtained from the different survey campaigns. To achieve a scientific result was used a software called Geomagic Qualify, that permits a comparison between the two meshes. Initially it was configured the "reference mesh", as the one with minus problems and major level of details and the "test mesh" as the one with less accuracy.
So it was decided to use the mesh came from the DSC as the "reference mesh" and the 3D model came from the WASC as the "test mesh".

The next step is "3D compare" between the meshes, setting for first an high tolerance range, with the central range (where the meshes are considered equal) between -0.07 and +0.07 mm and the acceptability range between -1.0 and +1.0 mm. When starting the calculation the software creates a view of the 3D model with a colour map applied on it according to the range. After this, with the command "create table" we can obtain a graphic chart with the trend of the differences (fig.8).

Subsequently the second procedure of "3D compare" between the meshes begins, setting a low tolerance range, with the central range between -0.001 and +0.001 mm and the acceptability range between -1.0 and +1.0 mm, finalizing also this second procedure with the trend of the differences between the meshes (fig.9).

Two different range are selected to know the extension of the error relative to the reduction of the acceptability of the process.

Observing both the resulting colour maps, one can seen an extended grey area, that represent the missing part of the second mesh, so the part that the software is not able to measure, resulting out of range.

Moreover one can see on the high tolerance resulting colour map that the major part of the area of the statue is green, with some small areas in light blue and yellow, as the ones with some differences in the "test mesh" in negative or in positive according to the "reference mesh". These parts are more extended in the low tolerance colour map, even if they remains linked to the same areas, as the ones with a more shiny surface (the nose of the boar), or more dark surface (the stomach and the paws).

In particular the shiny parts of the boar are resulted with negative deviations, while the dark parts are resulted with positive deviation.

**Considerations**

The photographic campaign called DSC has been executed in the best ways, so it can be considered the better possible model from a photogrammetric survey for this object using the selected tools. Some improvements are possible when only using reflex cameras with a higher number of pixels and by raising the quality parameters of the software (and last, but not least, using more advanced software solutions the future may bring...).

Moreover the undercut portions and the posterior surfaces of the statue which are surely less interesting and accessible by the tourists and the amateur photographers, are not present at all on the model, and consequently there was nothing found on the web archives.

The most significant error have been created on the surfaces with more reflectance (difficult to photographs avoiding the reflections). However the application of the texture enhances considerably the quality and with it the acceptability of the WASC resulting 3D model.

The differences in the lighting of the photos came from the web archive determine a less definition of the portions highly sculptural of the model, like the fur of the boar with the joints between the body and the limbs and the teeth.
Conclusions

In conclusion it was the WASC resulting 3D model that quickly describes the object of interest. However, this 3D model does not cover the entire surface of the object and so it is not suited for any scientific aims. The DSC resulting 3D model, instead, has more acceptable results: both sparse and dense pointcloud, mesh and texture are all very well defined; moreover the 3D model is complete, very precise and without any spikes compared with the WASC’s one. It could be used for scientific aims, publications and researches. Even if the WASC survey campaign can not create the right and optimal results for scientific aims, it can be considered as a good base to start thinking and projecting our real survey campaign, using the first one to better comprehend the volume peculiarity and with this the less accessible parts. Moreover one should consider an important reality: 3D models, now and in the near future, will be developed with the help of web archives, containing images, photos, but also three-dimensional models themselves. Many archives containing three-dimensional object of different types are already present in the web, and surely they will became much more widespread in the following years. In this way, various digital objects can be compared with other already present or with some other examples that will be built over years. Some reflections must be made also on the quick and exponential increasing of the quality and the pixel number on all the photographic equipment, both of the scientist and of the amateur and tourist; so it could be possible that in a very near future the resulting quality of a sort of a WASC will be more than acceptable. These kind of models are an interesting occasion to explore and study places and reality really far from us, not easily to access or, in the worst case, lost for various and never noble reasons like wars, abandon or lack of knowledge and culture. In recent days we are assisting to many and frequent attacks to the cultural heritage of Middle East countries, in case like these, that we would prefer that they had never happened and that do not occur in the future; preserving their memory with drawings, 3D models and so on is the only way to transmit knowledge to the future generations. To obtain the maximum results with these models and representations, is very important to report the issues due to the relationship of considerable immediacy between the shooting and the re-construction. This relation raises broader and open issues on rights, reproducibility, use of the data collected and therefore is responsibility of researchers to explore, use and make their own analysis tools and documentation in order to use them, primarily, for investigation and knowledge.
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Fig. 2 – The “Fontana del Bacchino” in the Boboli Gardens, Florence (Copyright: static.panoramio.com)
Fig. 3 – The “Fontana del Porcellino” in the Hall of the New Market, Florence (Copyright: static.panoramio.com)

Fig. 4 – The “Fontana del Porcellino” in the Hall of the New Market, Florence. Photo taken during the DSC (Copyright: Andrea Pasquali)
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Fig. 6 – Results of the Direct Survey Campaign: sparse pointcloud, dense pointcloud, mesh and textured 3D model (Copyright: Angela Mancuso, Andrea Pasquali)
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