HERITAGE and TECHNOLOGY
MIND KNOWLEDGE EXPERIENCE
XIII International Forum Le Vie dei Mercanti
Aversa, Capri 11-12-13 June 2015

Heritage and technology: novel approaches to 3D documentation and communication of architectural heritage

Mariateresa GALIZIA,[1,3] Laura INZERILLO[2,3] Cettina SANTAGATI,[1,3]
(1) Department of Civil Engineering and Architecture, University of Catania, Catania, Italy
E-mail: mgalizia@dau.unict.it; cettina.santagati@dau.unict.it
(2) Department of Architecture, University of Palermo, Palermo, Italy
Email: laura.inzerillo@unipa.it
(3) Department of Communication and Smart Transport, 3D Technologies and Augmented Reality, Euro-Mediterranean Institute of Science and Technology (IEMEST), Palermo, Italy
Email: laurainzerillo@iemest.eu, mariateresagalizia@iemest.eu, cettinasantagati@iemest.eu

Abstract
In the past few years we have seen a drastic increasing of image-based modeling (IBM) techniques to get high quality reality-based 3D models. The low costs of these techniques as well as their attractive visual quality have lead many researchers and professionals to invest their energies and resources in several tests. The use of IMB in the field of cultural heritage is mostly exploited in applications such as documentation, digital restoration, visualization, inspection, planning, AR/VR, conservation and design.
One of the strengthen of multi-view stereo techniques is the possibility to capture millions of points in a very short time and to get a 3D textured polygonal model that can be easily used for visualizing and communicating digital assets.
Currently, we can distinguish between desktop and web based packages. If the first one needs a high performance computer for data processing, the second one use the power of cloud computing to carry out a semi-automatic data processing instead of considerably slowing-down the computer. The aim of this study is to compare two of the most known IBM packages (Agisoft Photoscan and Autodesk Recap) in applications dealing with architectural heritage.
The comparison among the chosen packages are typical user-oriented parameters such as: visual completeness/detail of the 3D model; ratio between images resolution/number of images/time processing; number of used/discharged images (useful to optimize the images network); metric accuracy; learning curve/usability.

Keywords: Digital Heritage, Structure from motion, Architectural Heritage, 3D modeling

1. Introduction
Today, the accurate and detailed reconstruction of geometric models of real objects has become a common process. The diffusion of Image-based 3D modeling techniques, through image-based free, low cost and open source software, have increased drastically in the past few years, especially in the sector of Cultural Heritage (Architecture, Archeology, Urban planning). Currently, we can distinguish between desktop and web based packages. If the first one needs a high performance computer for data processing, the second one use the power of cloud computing to carry out a semi-automatic data processing instead of considerably slowing-down the computer. In both cases the output is a 3D textured model of the object of interest.
Our research investigates the limits and potentialities of 3D models obtained by using Autodesk Recap (web based) in comparison with Agisoft Photoscan (desktop) in Architectural Heritage field, in order to verify the applicability of the method for the practitioner purpose. Our goal is to evaluate both IBM packages efficiency, accuracy, constraints and limitations in order to provide insight into the current state of 3D modeling products. Our methodology forecasts the comparison between IBM models and terrestrial laser scanner 3D acquisition in order to verify metric accuracy.
To achieve this goal we chosen three interesting case studies: a frescoed vault, a lava portal with geometrical and sculptural elements, and a 360 degrees sculptural element.

2. Employed packages

2.1 Agisoft PhotoScan

Agisoft PhotoScan is an advanced image-based 3D modeling solution aimed at creating professional quality 3D content from still images. Based on the latest multi-view 3D reconstruction technology, it operates with arbitrary images and is efficient in both controlled and uncontrolled conditions. Photos can be taken from any position, providing that the object to be reconstructed is visible on at least two photos. Both image alignment and 3D model reconstruction are fully automated.

In the photographs alignment stage, PhotoScan searches for common points on photographs and matches them, as well as it finds the position of the camera for each picture and refines camera calibration parameters. As a result a sparse point cloud and a set o f camera positions are formed. The point cloud represents the results of photos alignment and will not be directly used in the further 3D model construction procedure (except for the point cloud based reconstruction method). However, it can be exported for further usage in external programs. For instance, the point cloud model can be used in a 3D editor as a reference.

On the contrary the set of camera positions is required for further 3D model construction by PhotoScan.

The building geometry is based on the estimated camera positions and pictures themselves a 3D polygon mesh, representing the object surface, is build by PhotoScan. Four algorithmic methods available in PhotoScan can be applied to 3D mesh generation: Arbitrary - Smooth, Arbitrary - Sharp, Height field - Smooth and Height field - Sharp methods. Additionally there is a Point Cloud based method for fast geometry generation based on the sparse point cloud alone.

Having built the mesh, it may be necessary to edit it. Some corrections, such as mesh decimation, removal of detached components, closing of holes in the mesh, etc. can be performed by PhotoScan. For more complex editing you have to engage external 3D editor tools. PhotoScan allows to export the mesh, edit it by another software and import it back. After the geometry (i.e. the mesh) is constructed, it can be textured and/or used for orthophoto generation.

Therefore, we propose interesting examples applied in architectural heritage field from the detail to the large scale.

2.2 **Recap 360**

ReCap 360 is a cloud-based photogrammetry service able to create 3D textured mesh and point clouds from photos. Taking advantage of the photogrammetric approach and algorithms of Computer Vision, the service reconstructs the internal parameters of the camera and the position in space of homologous points between frames starting from the correspondence between a sequence of photographic images acquired in an appropriate manner. The service acts in a semi-automatic way. The user creates the project, chooses the resolution of the model (low, ultra), the smart cropping and/or texturing option, the export format (eg OBJ). Then the images are uploaded and sent to the cloud. The user is adviced by email when the model is ready. Then he can improve the model itself by adding survey points or reference distance and manually stitching photos and then resending it to the cloud.

The model thus obtained, in OBJ format can be imported into dedicated software for 3D modeling and rendering.

As for the previous software, a crucial phase is the realization of the photographic network of the object: it is recommended that the angle between one shot and another is about 5-10 degrees so that the overlapping between neighboring frames is of about 70%; furthermore the images around the object should be taken with different rotations and different heights so as to vary the angle of the shoot.

The experiments conducted so far are very promising even when using amateur cameras. Using professional cameras with a fixed focal length and low distortion may improve the visual and metric quality of the obtained models.

3. Methodology

The applied methodological procedure is formuled as follows:

- Identification of substantials case studies;
- Creation of the images network in accordance to the identified case studies;
- Creation of 3D models by using the two chosen packages;
- 3D acquisition of the reference scans by means of 3D laser scanner;
- Comparative analysis of visual and metric accuracy.
- Interpretation of the results.

4. Case studies

The case studies have been chosen according to the diversity of the geometrical and materical features of the objects: the frescoed vaulted system of the Sant' Antonio di Padova church's choir, which is formed by a semi-cylindrical surface closed at an end by a semi-spherical cap; the splayed lava stone portal of the southern façade of the church Santa Maria Assunta in Randazzo, which is characterized by geometrical and bas-relief elements; a 360 degrees decorated console with two lateral winged lions realized for the National Exhibition held in Palermo between November 1891 and June 1892.

4.1 Frescoed vault in the Church of Sant'Antonio di Padova in Acireale (Catania)

Mariateresa Galizia

The cycle of frescoes that decorate the choir of the church of San Antonio di Padova depicts the glory of Sant'Antonio. It was made in 1755 by the famous local painter Pietro Paolo Vasta and, at his death, it was concluded by his son, Alexander. The church, considered the oldest in the city, was built in 1466 in the city center after the black death that affected the territory of Aci and it was dedicated to St. Sebastian martyr. On July 13, 1652 the church was consecrated to Sant'Antonio di Padova. Over the centuries the church was damaged by several earthquakes, thus requiring several repairs. The plan is a single nave with a barrel vault with lunettes, the choir is covered by a barrel vault and the semicircular apse by a semi-spherical cap.

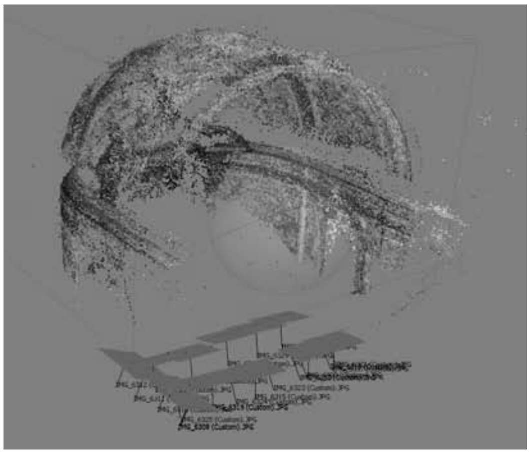

Fig. 1: Image of the frescoed vault and its dataset.

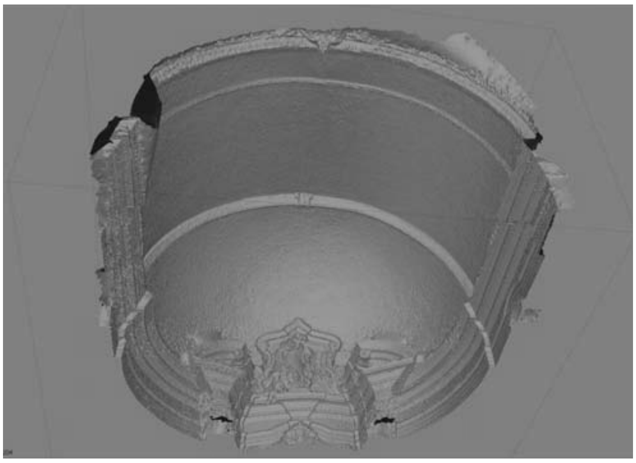

Fig. 2: Photoscan textured and shaded 3D model.

Fig. 3: Recap textured and shaded 3D model.

The images were taken with Canon Eos 5D Mark II, 24 mm lens and at a resolution of 12 Mpix. The shot project toke in account the geometrical features of the vaulted surfaces and the presence of the frescoes. Therefore, two lines of zenithal overlapping images were taken in order to guarantee surface covering (except for areas occluded by overhangs) for a total of 24 shots. The poor natural lighting conditions required the use of an appropriate photographic set.
We then proceeded to the creation of the models by using the two chosen software.
The test conducted on Photoscan focused on the optimization of image alignment and geometry reconstruction parameters according to the geometric features of the surfaces to be reconstructed. As regards the alignment we chose to perform a full automatic alignment giving high accuracy to camera pose estimation. In the following geometry reconstruction step we chose smooth and high parameters. At the same time the processing was started in Recap uploading the images and launching on the cloud the 3D reconstruction.
Table 1 shows data concerning the two experiments carried out.

Frescoed vault in the church of San Antonio di Padova Lenght 6 .22 m width 5.20 m height 3.05 (9.20) m		
	Photoscan	**Recap**
# photos	24	24
# photos	0	0
Camera	Canon Eos 5D Mark II	Canon Eos 5D Mark II
Camera resolution	4308x2872	4308x2872
Lens	24 mm	24 mm
Processing time	4h e 20 min (on desktop)	2h (on cloud)
Sparse point cloud	83291	-
Mesh	7.150.000	1.900.000

Tab 1. Frescoed vault in the church of San Antonio di Padova processing information

4.2 Portal of the Church of Santa Maria Assunta in Randazzo (Catania)

Cettina Santagati

The southern portal of the church of Santa Maria Assunta in Randazzo is datable to around the early XVI century when the church, built in the early XIII century, undergoes several changes. The portal, in lava material, has solomonic decorated columns and a structure with multiple registers. It has an architectural composition with lunettes overlaid with round arches, one of them adorned with a small marble statue of the Madonna. The portal is framed by pilaster strips with composite capitals surmounted by a simplified entablature decorated with phytomorphic Gothic motifs (branch of vine), as well as a late Gothic column with spiral shaft and with a type of classicists decorative motifs like the large tile with rosettes but also diamond-point ashlars.

Fig. 4: Image of the portal and its dataset.

Fig. 5: Photoscan textured and shaded 3D model.

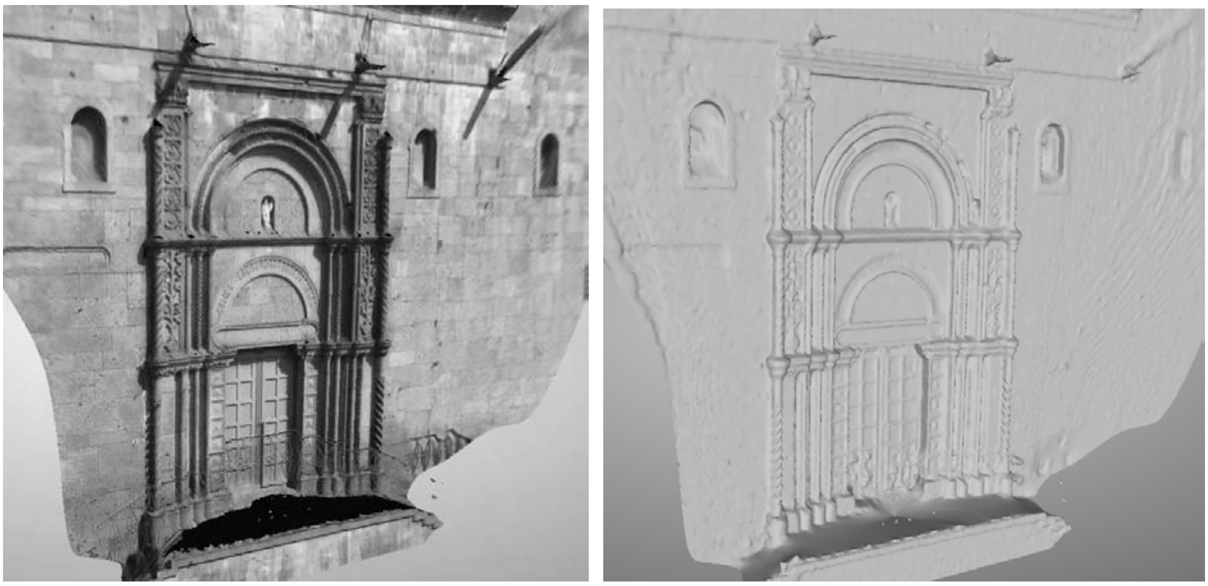

Fig. 6: Recap textured and shaded 3D model.

The images were taken with Nikon Coolpix E8800, 24 mm lens and at a resolution of 8 Mpix. The shot project toke in account the geometrical and decorative characteristics of the portal. Thus, it was planned to perform two semi-circular paths around the object at different eights shooting 33 convergent images.
We then proceeded to the creation of the models by using the two chosen software.
In this case, the processing on Photoscan foresaw the setting of aligment parameters in accordance to what previously tested. As regards geometry reconstruction, after having carried out several test both in sharp and

in smooth mode, we decided to use smooth mode (able to make a watertight without holes reconstruction) combined with ultra high mode so that to describe with more detail the geometry of Solomon columns and bas-rielief. At the same time the processing was started in Recap uploading the images and launching on the cloud the 3D reconstruction.
Table 2 shows data concerning the two experiments conducted.

Southern portal of the church of Santa Maria Assunta lenght 7,08 m height 10,70 m		
	Photoscan	**Recap**
# photos	33	33
# photos	0	0
Camera	Nikon Coolpix 8800	Nikon Coolpix 8800
Camera resolution	4308x2872	4308x2872
Lens	24 mm	24 mm
Processing time	29h e 54 min (on desktop)	90 min (on cloud)
Sparse point cloud	68774	-
Mesh	4.500.000	1.900.000

Tab 2. Southern portal of the Church of Santa Maria Assunta processing information

4.3 Plaster Architectural Element (Palermo)

Laura Inzerillo

The National Exhibition, dedicated to industry, commerce, agriculture and Fine Arts, was held in Palermo between November 1891 and June 1892. The project was committed to the young architect Ernesto Basile, assisted by engineers Ernesto Armò, Lodovico Biondi e Alfredo Raimondi, in 1888.
The Exhibition showed partial or whole reproductions of the major Sicilian monuments and was organized into three different sectors. In the first one there were the plasters, archetypes and facsimiles, works still present and exhibited into the spaces of the Department of Architecture of the University of Palermo.
Our experimentation has been focused on the 3D reconstruction of a plaster: a decorated console with two lateral winged lions.
The challenge was to carry out a closed 3Dmodel of a complex shape and, below you can observe the different result achieved by Photoscan and Recap.

In the figure below is showed the data set of 57 photos.

Fig. 7: Images of the two different sides of the console and its dataset.

Fig. 8: Photoscan result: textured and shaded 3D model.

Fig. 9: Recap result: textured and shaded 3D model.

We used Nikon D3200 E8800 camera, with 24mm lens and 12 mpix resolution. The criteria for data acquisition have considered the wealth of decorative reliefs and winged lions, and the need of having to document the shelf at 360 °, providing an overlap b etween shots and the other. Therefore, they were made 57 sockets.
The models carried out, were made using the two software identified.
Also in this case, the processing of PhotoScan provided for the setting of the alignment parameters in accordance to what was previously experienced.
The complexity of the surfaces to be reconstructed, has guided the choice of smooth and ultra high parameters.
At the same time, the development was also launched in Recap uploading photographic images and launching cloud reconstruction.
In Table 3 are shown the data concerning the two experiments conducted.

Plaster architectural console width 0,81 m height 0,80 m depth 0,17 m		
	Photoscan	**Recap**
# photos	57	57
# photos	0	0
Camera	Nikon D3200	Nikon D3200
Camera resolution	4312x3000	4312x3000
Lens	24 mm	24 mm
Processing time	40h 27m (on desktop)	120 min (on cloud)
Sparse point cloud	127.645	-
Mesh	3.138.961	834.565

Tab 3. Plaster architectural console processing information

5. Results

The obtained models have been scaled and aligned in Meshlab with the corresponding models got by means of 3D scanners (Leica Geosystem HDS 3000 and Vivid Minolta 9i) and Haussdorff distance between the aligned model and the reference scan has been processed. The calculation range has been assigned according to the objects size: 0.05-0.00 m for the vault and the portal, 0.01-0.00 m for the console.
The deviation between compared models, in terms of homologous points distance, can be easily achieved by evaluating “vertex quality function” and “per vertex quality histogram” and by visualizing the model in “colorize by vertex quality” mode and “showing the histogram”. The vertex are colored according to a range that spans from red (deviation equal to 0) to blue (deviation ≥ to maximum value).
Figures 10, 11 and 12 show the results of the Haussdorff distance evaluation: the blue color corresponds to vertex that are outside the calculation range, that is there are no overlapping between the scan and the 3D reconstructed model.
Effectively, both in the case of the vault and of the portal, the maximum deviation begins to be appreciable starting from 0.016 m value both for Photocan and for Recap models. As regards the console, the maximum appreciable deviation starts from 0.0035 m.
Furthermore, the histograms show the deviations distribution (in terms of number of interested vertex) and the miscalculation error of the 3D geometry.

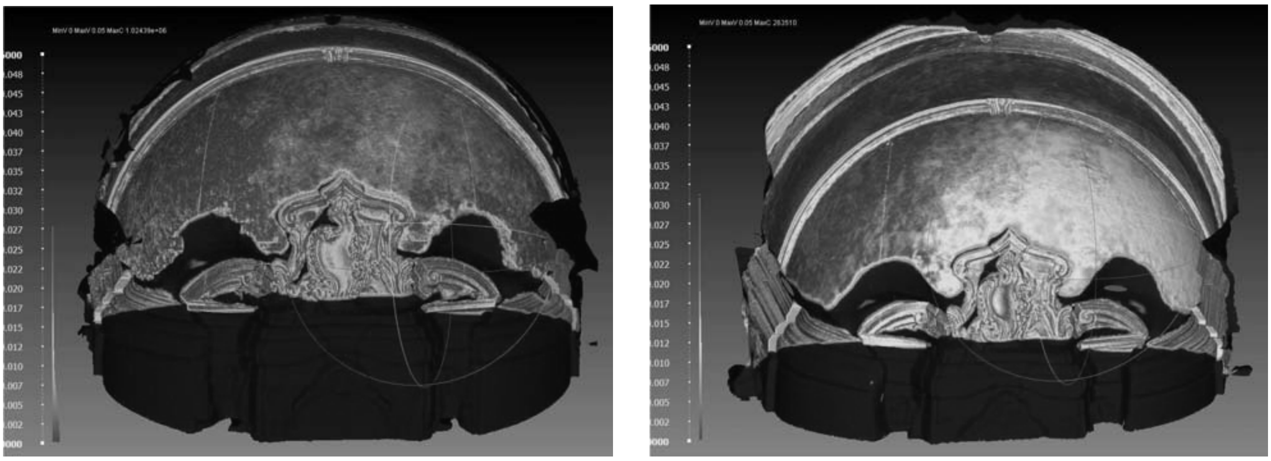

Fig. 10: On the left comparison between TLS and photoscan model, on the right comparison between TLS and Recap model and related quality vertex histograms calculated on Haussdorff distance.

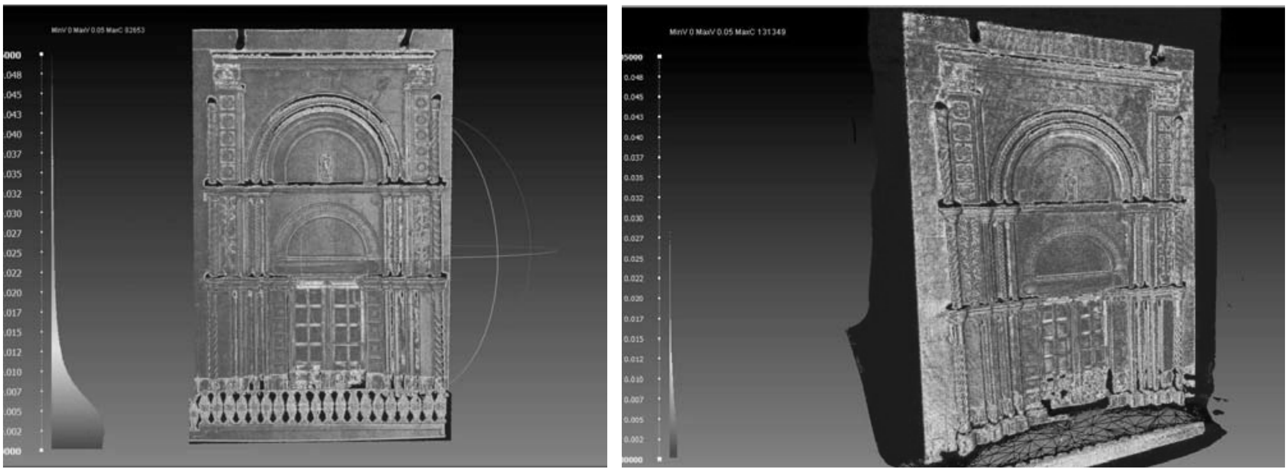

Fig. 11: On the left comparison between TLS and photoscan model, on the right comparison between TLS and Recap model and related quality vertex histograms calculated on Haussdorff distance.

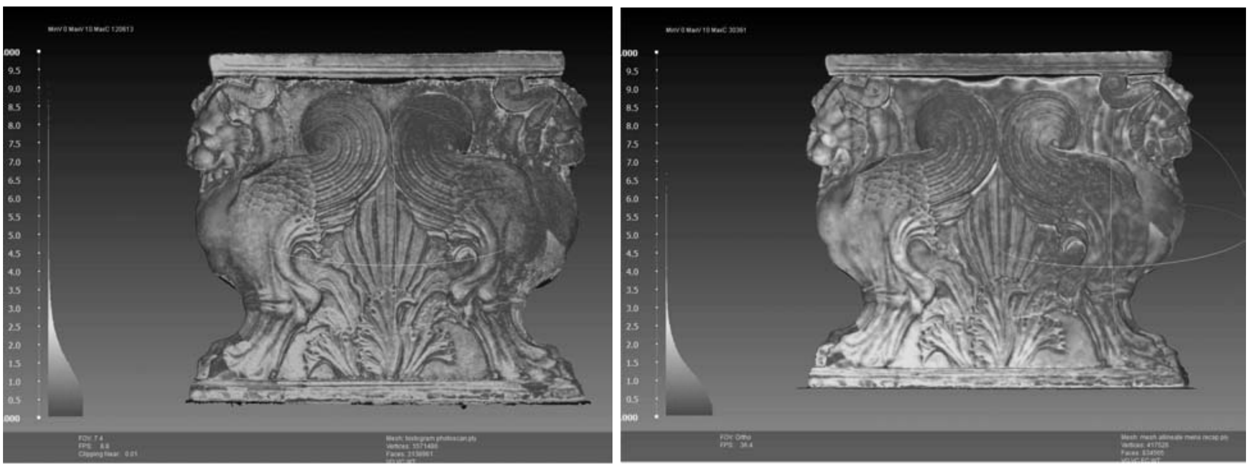

Fig. 12: On the left comparison between TLS and photoscan model, on the right comparison between TLS and Recap model and related quality vertex histograms calculated on Haussdorff distance.

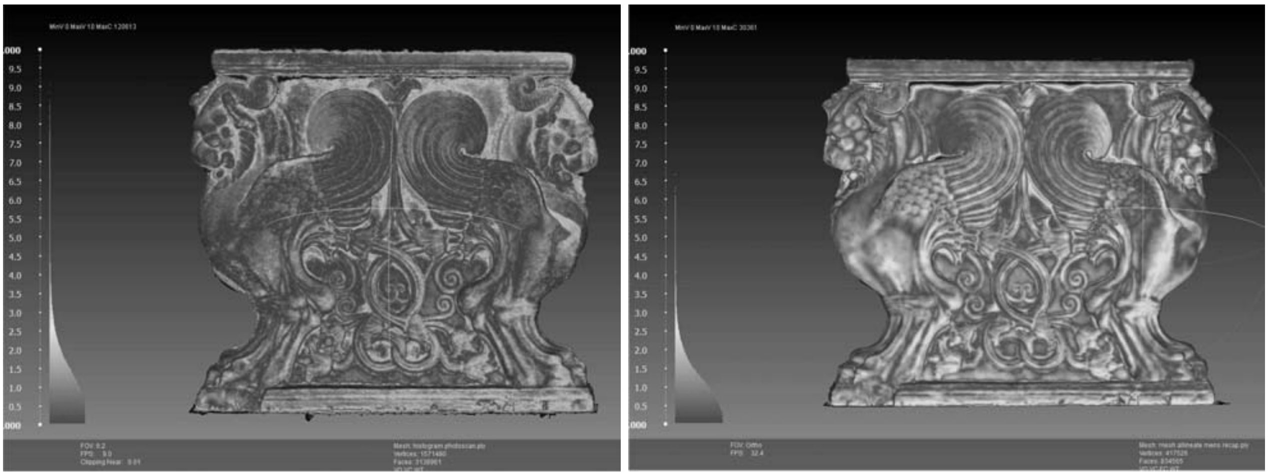

Fig. 13: On the left comparison between TLS and photoscan model, on the right comparison between TLS and Recap model and related quality vertex histograms calculated on Haussdorff distance.

6. Conclusion

Finally, we can deduce some practical considerations on the use of the two packages. We have to take into account the following parameters: required hardware, time processing, visual completeness and detail of the 3D model, metric accuracy and learning curve/usability.

Hardware: *Photoscan*. It is necessary a high hardware profile for models reconstruction. To process up to 200-300 images at a resolution of 10 Mpx, are required 12 GB of RAM. Furthermore, in presence of a professional graphics hardware, it is possible to exploit graphics OPEGL.
Recap. There are no particolar requisite except the use of Google Crome as browser.

Time processing: *Photoscan.* The tests conducted in this study show a time processing that spans from 4 up to 40 hours depending on the number of images and the reconstruction accuracy.
Recap. This package works on the cloud, exploiting the avaliable servers. Time processing takes few hours.

Learning curve: *Photoscan.* Learning curve requires a preliminary knowledge of the fundamental algorithms for mesh reconstruction. The final results are affected by the choice of the reconstruction parameters.
Recap. This package acts like a black box. The user uploads the images and, if needed, stitches homologous points on the images to scale the model or improve the 3D reconstruction.

Visual completeness: *Photoscan.* The visual completeness and the detail of the obtained 3D models depends on the parameters set for the reconstruction, as well as on the images network.
Recap. The visual accuracy of the got 3D models is function of the images dataset and of the images resolution.

Metric accuracy: *Photoscan.* As it is shown in the histograms, the deviation between the reconstructed 3D model and the reference scan depends on the size of the object. In the case of the vault and the portal the deviation spans a range equal to 0.016-0.00 m, as regards the console it is equal to 0.004-0.00 m.
Recap. For this package, the histograms clearly show that in the case of the vault and the portal the deviation spans a range equal to 0.02-0.00 m, as regards the console it is equal to 0.003-0.00 m.

In conclusion, we could assert that nowadays technology offers packages that allow to get novel approaches to the traditional 3D documentation and communication of the architectural cultural heritage. This comparative study indicates the pipeline to choice according the final purpose of 3D reconstruction.

Bibliographical References

BANDIERA Adriana, BERALDIN Jean-Angelo, GAIANI Marco. Nascita ed utilizzo delle tecniche digitali di 3D imaging, modellazione e visualizzazione per l'architettura e i beni culturali. *"Ikhnos"* . Lombardi editore, Siracusa, 2011. pp. 81-134.

BERTOCCI Stefano, BINI Marco. *Manuale di rilievo architettonico e urbano*. Novara: CittàStudi, 2012.

GALIZIA Mariateresa, SANTAGATI Cettina (2013). Low-cost image-based modeling techniques for archaeological heritage digitalization: more than just a good tool for 3D visualization? *Virtual Archaeology Review*. 2013. 4 (9), nov 2013, 123-129

KERSTEN Thomas, LINDSTAEDT Maren, Image-Based Low-Cost Systems For Automatic 3d Recording And Modelling Of Archaeological Finds And Objects. M. Ioannides et al. (Eds): Progress in Cultural Heritage Preservation, EuroMed 2012, 7616 LNCS, Pp 1-10.

INZERILLO Laura, SANTAGATI Cettina. Il progetto del rilievo nell'utilizzo di tecniche di modellazione dense stereo matching. *Disegnare Idee Immagini.* 47. 2013. Gangemi, Roma, 82-91

INZERILLO Laura, SANTAGATI Cettina, GALIZIA Mariateresa. Il Portico meridionale della Cattedrale di Palermo: sperimentazioni di rilievo attraverso l'utilizzo di tecniche Structure from Motion, in P.Giandebiaggi, C.Vernizzi (a cura di), Italian survey & International experience edizione bilingue italiano e inglese, Roma: Gangemi editore, 2014. pp 877-886

REMONDINO Fabio, EL-HAKIM Sabry (2006). Image-based 3-D modelling: a review. *The Photogrammetric Record*, 2006. 21(115), 269–291.

REMONDINO Fabio, DEL PIZZO Silvio, KERSTEN Thomas, TROISI Salvatore. "Low-Cost and Open-Source Solutions for Automated Image Orientation–A Critical Overview". M. Ioannides et al. (Eds): Progress in Cultural Heritage Preservation, EuroMed 2012, 7616 LNCS, pp. 40-54.

REMONDINO Fabio, SPERA Maria Grazia, NOCERINO Erica, MENNA Fabio, NEX Francesco. State of the art in high density image matching. *The Photogrammetric Record* . 2014. 29 (146), 144-166

RODRÍGUEZ-NAVARRO, Pablo. Automated Digital photogrammetry versus the systems based on active 3D sensors - La Fotogrametría Digital Automatizada frente a los sistemas basados en sensores 3D activos. *Revista EGA*, nº. 20, año 17, 2012, Valencia, pp. 100-111

SANTAGATI Cettina, INZERILLO Laura, DI PAOLA Francesco. Image-based modeling techniques for architectural heritage 3D digitalization: limits and potentialities. International *Archives of the Photogrammetry, Remote Sensing and Spatial Information Sciences* , 2013, XL-5(W2), 550-560.

SANTAGATI Cettina, INZERILLO Laura. 123D Catch: efficiency, accuracy, constraints and limitations in architectural heritage field. *International Journal of Heritage in Digital Era*. 2013. 2 (2), 263-290