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THE GALLERY OF THE CASTROMEDIANO'S CASTLE. THREE-DIMENSIONAL RECONSTRUCTION AND VIRTUAL REPRESENTATION

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Abstract

The Ducal Castle Castromediano–Limburg was built around the sixteenth century in the historic centre of Cavallino, a town renowned for its excellence in the arts and culture, located in Salento south of Lecce (Italy). The Castle, also known as Ducal Palace, was the home of the illustrious Duke Sigismondo Castromediano, a man of great culture, archaeologist, writer and indomitable patriot of the Italian Risorgimento. The Gallery, which is one of the most important part of the castle, is a magnificent reception hall richly decorated and adorned by numerous sculptures. Today, the magnificent Gallery shows the signs of aging and improper use. Therefore, a restoration of the spaces has already been planned. The Gallery of Castromediano's Castle, classified as heritage of significant cultural and artistic importance, was the subject of a digital acquisition project, a three-dimensional reconstruction and virtual representation performed by CEIT (Euro-Mediterranean Centre for Technology Innovation for the Cultural and environmental Heritage and Biomedicine). The high-resolution 3D digital acquisition was performed using a time-of-flight 3D laser scanner and a campaign of photographic shooting of the frescoed surfaces. A 3D model, at two different levels of detail (LoD), was created, in full color, along with the animation of the model according to a predefined path that allows the user to enjoy, by various media, a virtual tour of the Gallery in a guided, detailed, complete and full-immersive way. The high-resolution 3D model will be a useful tool for the future conservation and restoration of the Gallery. It can be consulted and\or updated remotely for in-depth studies of historical and artistic nature.

Keywords

Gallery, Castromediano's Castle, Ducal Palace, Castromediano-Limburg, Cavallino (LE), Three-dimensional reconstruction, Virtual representation, 3D models, Cultural Heritage

1. *Cavallino, City of Art and Culture*

Cavallino is a town of 12,600 inhabitants in the Salento peninsula, south of Lecce, Italy. In the past it was an important messapic center, as shown by the archaeological finds preserved for the most part in the Provincial Museum "Sigismondo Castromediano" of Lecce.

Nowadays it is recognized as a City of Art and Culture, renowned for its excellence in the Salentine arts and culture. Cavallino hosts the High School ISUFI, the School of Archaeology of the University of Salento and the Messapic Diffuse Museum.

The sixteenth century Ducal Castle Castromediano-Limburg with its splendid seventeenth century Gallery, is one of the most important building among several historic and religious buildings that can be admired in the historic center of the town.

2. *The Castromediano's Castle*

The Castle, also known as the Ducal Palace, was the home of the illustrious Duke Sigismondo Castromediano, a man of great culture, archaeologist, writer and indomitable patriot of the Italian Risorgimento.

The Palace, which takes its name from the family that obtained the fief of Cavallino in 1447, has a beautiful portal and a bastion of the sixteenth century.

Inside the atrium we can admire a huge statue, called "the giant", which depicts Kiliano of Limburg, founder of the Castromediano's family, in seventeenth century clothes.

The Gallery adorned with zodiac symbology, the chapel of St. Stephen, and other rooms such as the sitting room and the weapons room, are all of great importance and most of them belongs to the Gorgoni family, who are Castromediano's heirs.

3. The Gallery of Castromediano's Castle

Numerous ancient sources refer to the Gallery of the Ducal Palace as a richly decorated, magnificent reception hall (Fig. 1). Several scholars consider it as one of the most beautiful rooms of patrician residences in the province of Lecce, worthy of a real castle.

Fig. 1: Cavallino. The Gallery of the Castromediano's Castle. South side

Today, the magnificent Gallery shows the signs of aging and improper uses. In 1930, in fact, it was used as a tobacco factory and the decorations and sculptures were covered with lime for hygiene reasons.

In the late 70's, thanks to the interest of the Province of Lecce, the Municipality of Cavallino, and the commitment and foresight of Mr. Gaetano Gorgoni,[1] a phase of restoration, static consolidation, preservation and enhancement of the Gallery started. Over the years, the Gallery has become a public accesible cultural heritage. Furthermore, it's also becoming a renowned site of cultural, literary, artistic and historical events. The complete restoration of this jewel of Southern art is planned through a conservative and aesthetic restoration of the sculptures, paintings and floor. Recently the conservative and aesthetic restoration of two adjacent rooms at the Gallery has been performed, a living room and an alcove with the walls painted with floral motifs.

The Gallery is 24 meters long, 8 wide and 11 high. The floor was realized with glazed cement and it is rich in polychrome tiles that form a pattern of stars, which is repeated in the frescoes illustrating the vault, decorated with the symbols of the zodiac (Fig. 2).

The frescoes by Francesco Florio, representing the costellations of the Zodiac and other groups of stars among the most known in the firmament, makes the ceiling of the great hall shine. Animals and vigorous human figures, stand out clearly against the light blue background dotted with stars. (Fig. 3). The softness and elegance of the composition of these figures, combined with the prominence of the athletic and muscular forms led the scholar Cosimo De Giorgi to relate them to Michelangelo's style. The walls are decorated with numerous sculptures, arranged on two levels, created by the Palermitan sculptor Carlo Aprile and his disciples.

There are 12 stone statues of mythological characters placed high up to the wide cornice on which is set the vault. On the short sides, we can admire the half-length statues of nine characters of the House of Castromediano and the group that portrays Aeneas, who is carrying on his shoulder his father Anchises, who in turn holds the son of Aeneas, Ascanio (Fig. 4).

Halfheight, on stone shelves stuck in the four walls of the hall, there are fifteen statues of local

[1]G. Gorgoni, Castromediano's heir, Deputy Mayor and delegated to Culture and the Environment of the City of Cavallino (Lecce), already Mayor of the same City, Councilor for Cultural Heritage and Tourism of the Province of Lecce (Italy), Deputy to the Italian Parliament: http://www.senato.it/leg/ElencoParlamentari/Parlg.html; http://www.ceit-otranto.it/images/documents/cv_on_ggorgoni.pdf.

stone (originally 16), representing the virtues. Each one is about two meters tall. We can read the Latin name of the represented subject in the corbel of each statue (Fig. 5). The shelf that once

Fig. 2: Cavallino. The Gallery of the Castromediano's Castle. Floor details.

Fig. 3: Cavallino. The Gallery of the Castromediano's Castle. Frescoes of the sky of the great hall. Respectively north side (l.) and south side (r.).

Fig. 4: Cavallino. The Gallery of the Castromediano's Castle. Stone statues on the cornice. In the center of the right image: Enea, Anchise and Ascanio.

Fig. 5: Cavallino. The Gallery of the Castromediano's Castle. Some statues on shelves.

Fig. 6: Cavallino. The Gallery of the Castromediano's Castle, south side (l. and c.); north side (r.)

held the statue of Fortune is empty, and it appears to have been intentionally destroyed, at the beginning of 1800, by the French soldiers arrived in Cavallino to stop a revolt started for the abolition of the fiefs.

A legend passed down within the family has it that the decline of the House of Castromediano started with the demolition of that statue.

The beauty of this precious treasure, which contains valuable expressions of architecture and art, fascinated big names of Italian and international culture, who have chosen the Gallery to present prestigious literary and artistic works, often in national preview.

The magnificent Gallery of the Castromediano's Castle is nowadays widely regarded as an architectural jewel where art and history come together in a setting of rare beauty and charm, a historical and artistic heritage of

great importance, also from a touristic standpoint, a place to enjoy and preserve (Fig. 6).

4. *The Three-dimensional reconstruction and virtual representation*

The Gallery of Castromediano's Castle, classified as heritage of significant cultural and artistic importance, was the subject of a digital acquisition project, a three-dimensional reconstruction and virtual representation (Beraldin, Picard, El-Hakim, Godin, Valzano, & Bandiera, 2005; Gaiani, Benedetti, & Apollonio, 2011) performed by the *Laboratory 3D Lab* and the *CEIT* (Euro-Mediterranean Centre for Technology Innovation for the cultural environmental heritage and Biomedicine)[2], based on a long experienced on this field[3].

The work of 2D and 3D digital acquisition and processing of the whole Gallery, including the frescos, the architectural structure and the various objects that compose it, such as statues and friezes, was quite complex and required the use of specific and consolidated methodologies that combine active acquisition with passive acquisition techniques (Bernardini, & Rushmeier, 2002; El-Hakim, Remondino, & Voltolini, 2008; El-Omari, & Moselhi, 2008; Remondino, 2011; Valzano, Bandiera, & Beraldin, 2005; Valzano, Bandiera, Beraldin, Picard, El-Hakim, Godin, Borgeat, Blais, Paquet, & Rioux, 2005) taking into account not only the size of the Gallery, but especially the height of the ceiling, as well as the space complexity due to the presence of statues placed on shelves (Fig. 7).

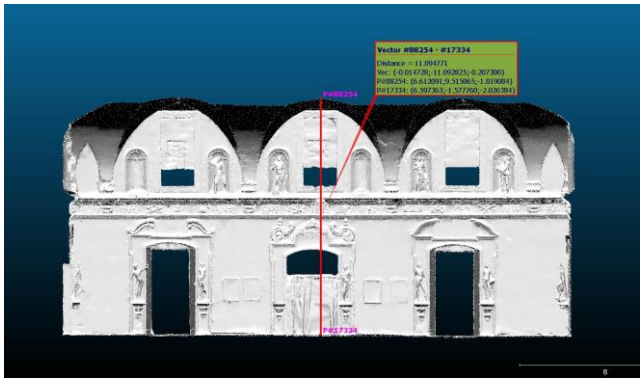

Fig. 7: Detection of the height of the hall by inspection of the 3D model.

The high-resolution 3D digital acquisition was performed using a time-of-flight 3D hemispheric laser scanner, with a wide field of view capable of acquiring large surface areas with a resolution up to 92 points per degree, and a subsequent campaign of photographic shooting to acquire the data on the surface characteristics, frescoed and not.

A 3D model, both in high and low resolution, was created, in full color, along with the animation of the model according to a predefined path that allows the user to enjoy, by various media, a virtual tour of the Gallery.

Operationally, we have adopted methodologies formulated over the last few years and widely applied in numerous settings (El-Omari, & Moselhi, 2008; Remondino, 2011) involving the reallocation of the real object into a digital model characterized by high geometric accuracy, on the one hand, associated with a superficial photometric restitution, on the other, able to guarantee a semantic reading of the object and its most minute artistic and architectural features.

To guarantee the metric-dimensional quality and reproduction of the surface characteristics required by the project, a procedural chain was adopted in the following phases:

a) acquisition of the metric, formal and superficial data of the Gallery;
b) 3D modeling;
c) polygonization and optimization of the model;
d) mapping of the 3D model;
e) production of animated scenes in stereo and monoscopic.

5. *The laser scanned point cloud processing*

The first phase saw the Tof laser scanner running with 39 hemispheric images for a total of approximately 15 billion points, equal to 199 Gigabytes of rough 3D data and the acquisition of 90 digital photographic shots.

In Fig. 8 we can see an example of planar development of one of the 39 scans.

As for the modeling phase, it is divided into a series of operational steps aimed at analyzing the acquired data, their subsequent filtering and masking, the alignment of the various scans and the final merge of the data aligned.

[2] Both Institutions are directed by Virginia Valzano, Scientific-Technical Coordinator of this project too.

[3] See Bibliography.

Fig. 8: Plane development of a hemispheric 3D scan

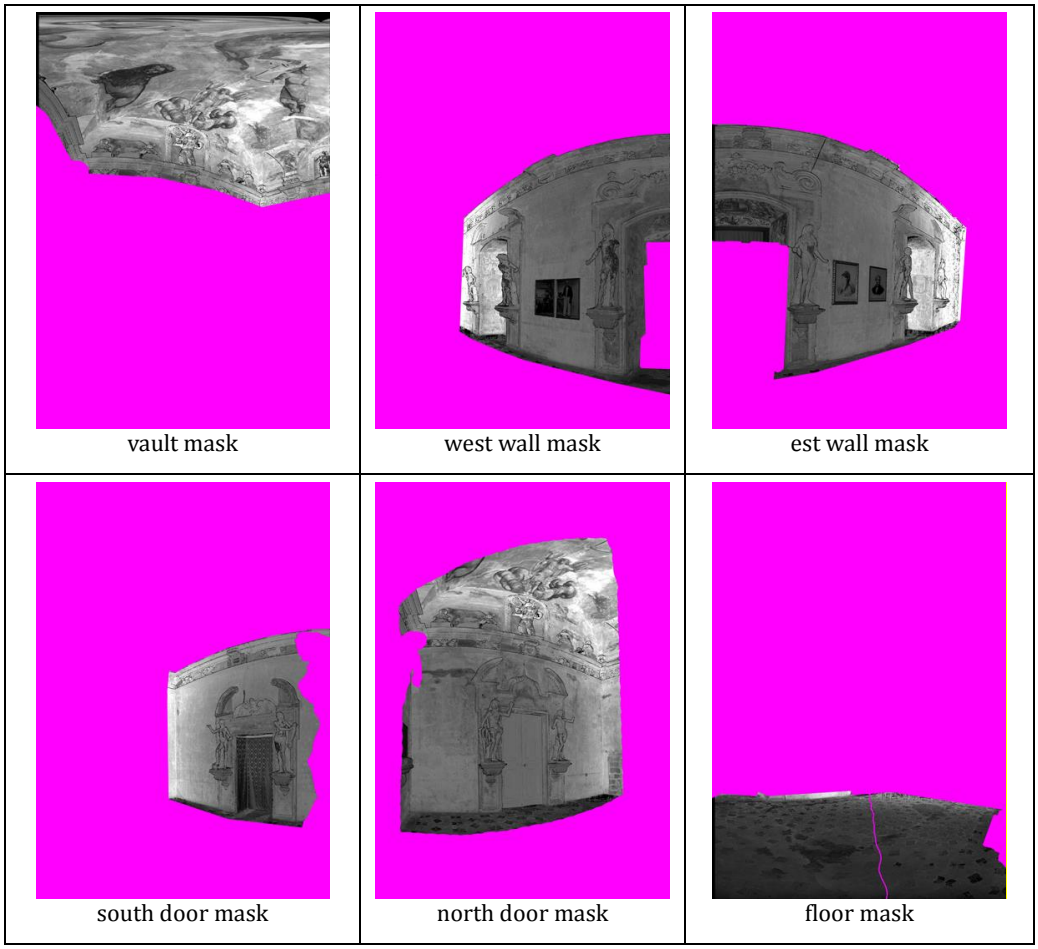

Fig. 9: Selection mask examples for some sections of the model

For the management and processing of the huge amount of raw data from scans, a specific analysis of individual acquisitions was performed by applying a set of filters capable of obtaining point clouds characterized by a spatial resolution differentiated for morphological characteristics and geometric features that characterize the single architectural element, equal to 5 mm for the vault and 2.5 mm for the doors, walls, decorative systems and the floor with recesses.

For this purpose, the Gallery has been divided into 6 semantic relevant sections: vault, floor, wall/north door, south wall/door, east wall, west wall.

processing programs used later in the process. The hemispheric point clouds has been divided into 4 more manageable clusters (0°, 90°, 180°, 270°). Th generated PNG files has been used as base for the

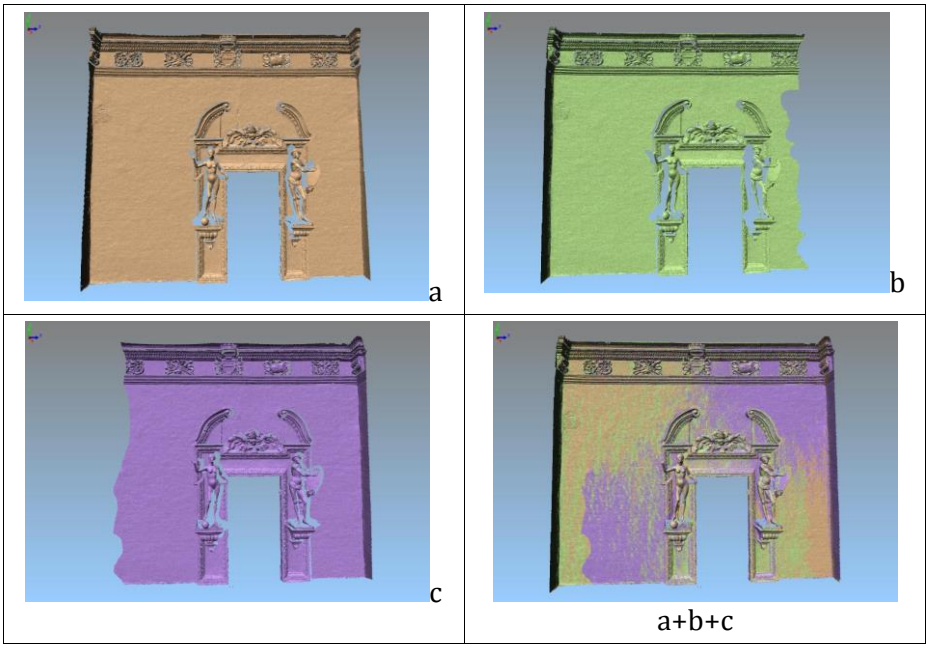

Fig. 10: Result of the alignment of three point clouds (a + b + c)

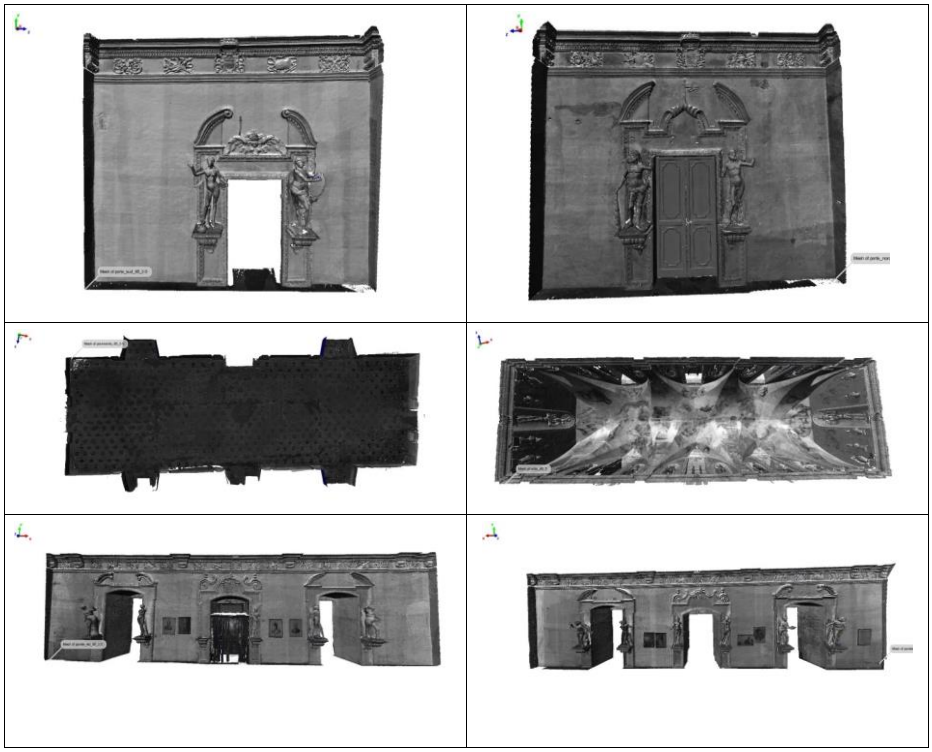

Fig. 11: Some snapshot of 3D models

A subsequent filtering and masking of scans was performed for each of the six sections. The raw files has been converted to be interpreted by the

generation of the selection masks.

The application of such masks allowed to isolate the model sections to be processed. Finally,

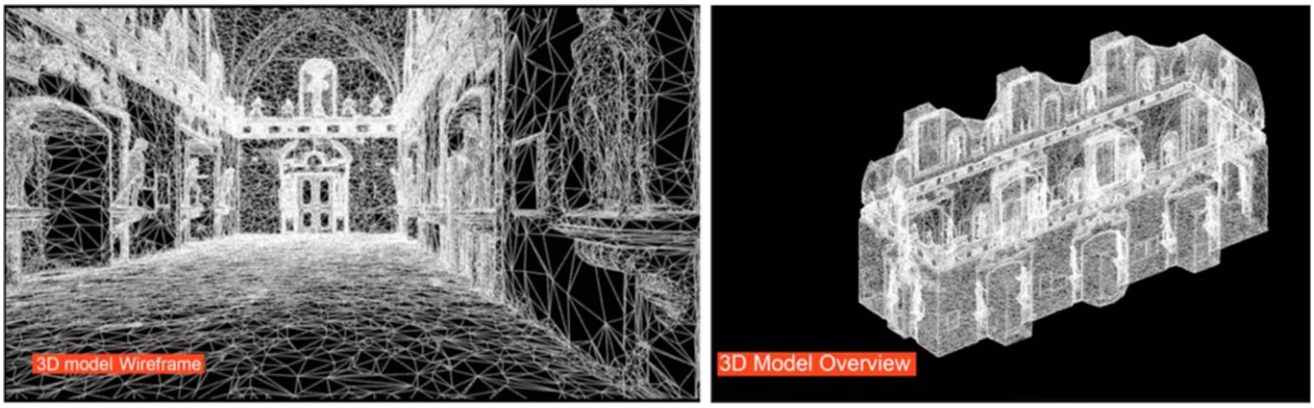

Fig. 12: 3D model WireFrame (l.); 3D model Overview (r.).

the processed data has been decimated, ensuring accuracy and data resolution in accordance with the specifications required by the project. Fig. 9 is a sample mask for some sections.

The next step saw the alignment of the various scans (point clouds) in a first step with the "point-to-point" method, where each scan was aligned with the previous one by locating a certain number of "points in Common" and then at the next refining using the Iterative Closest Point (ICP) algorithm, minimizing the distance between pairs of point clouds (Fig. 10).

The merging phase involved the transformation of point clouds that were previously aligned in complex polygon models, provided in this phase with chromatic information "color per vertex" in black and white. Thus, 3D models of high accuracy and complexity have been obtained, consisting of approximately 62 million polygons (Fig. 11).

Due to the high number of polygons obtained in the previous phase, it was necessary to reduce the resolution based on the template usage target. For 3D visualization in real-time stereography, it was reduced from over 62 million polygons to just over 6 million, so distributed:

- Vault: 1.000.000
- Floor: 1.000.000
- North door: 500.000
- South door: 500.000
- East wall: 1.500.000
- West wall: 1.500.000

The model thus obtained retains the monochrome information given by the intensity of the scanner at every point acquired, lacking any information related to the surface color (Fig. 12).

6. *Mesh optimization throught the data processing of photogrammetry and laser scanning datasets*

The missing colour informations has been integrated throught specially captured photo shoots used to create and mapping a full-color, two-level 3D model that can reproduce the status of the Gallery.

To replace the color intensity vertex map with a photographic full color texture, it has been operated as follows. Through the application Agisoft Photoscan, a set of 80 pre-processed photos (Fig. 13) of the Gallery has been aligned (generating a sparse point cloud). To obtain a better alignment it has been used an efficient pipeline based on color enhancement, image denoising, color-to-gray conversion and image content enrichment which increases the number of matching points between the photos increasing the contrast of the minute surface details, trough the elaboration of the high dynamic range pictures.

Subsequently, a dense point cloud has been automatically elaborated using Agisoft built-in algorithm based on artificial vision which matches the homologous points in the aligned photos, and uses inverse perspective constructions to find the intersections of the perspective rays locating the points in space. Once obtained the dense point cloud, it has been exported in ".ply" format, and imported in Cloud-compare, and, through error minimization methods, it has been aligned with the 3D model of the Gallery obtained from the laser scanning campaign. If the position of the dense cloud is set to be fixed, the 3D model of the Gallery can be imported in Agisoft Photoscan and it will perfectly match the dense cloud, and thus the set of aligned photos. This step is very important to

guarantee the correct projection of the photos onto the mesh, in fact, if the mesh and the dense cloud are not perfectly aligned or if there are discrepancies between the generated dense cloud and the aligned mesh, the final textures could appear blurred. Furthermore, if some photos are not correctly aligned or there are inconsistencies in the geometry they can occurs some ghosting effects or artifacts in the textures. Thus, is necessary to inspect every aligned photo and verify if they have been correctly placed before calculating the texture.

Sometimes is impossible to understand at a first glance if the photos are aligned correctly, thus it's necessary to calculate and apply the texture, and use it as a tool to check the correct alignment of the photos and the meshes. Once elaborated, and applied to the model, it must be carefully

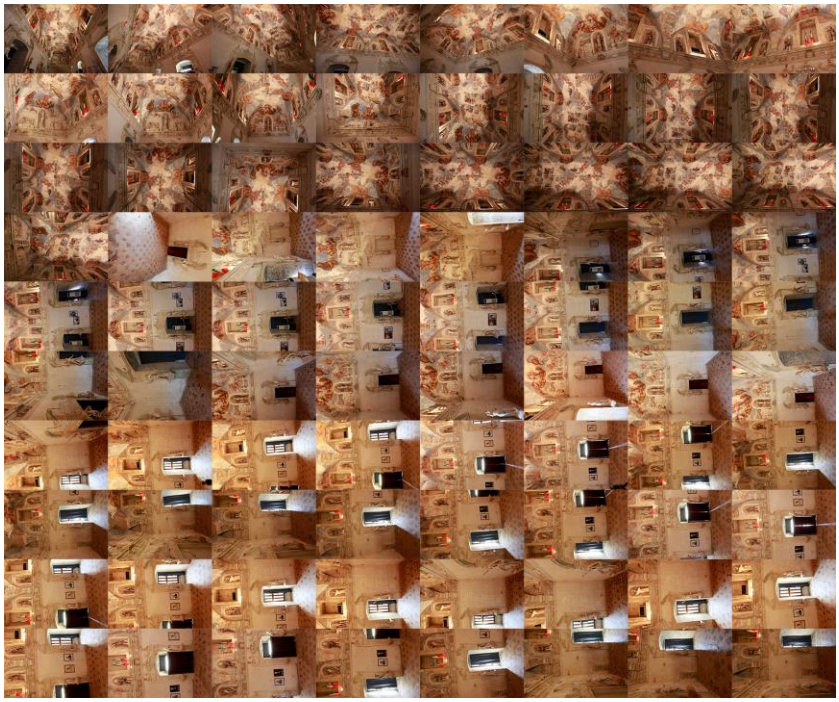

Fig. 13: Gallery of the Castromediano's Castle: Data set 80 images

Fig. 14: Gallery of the Castromediano's Castle: 8 bitmaps texture

checked, looking for the abovementioned ghosting effects and artifacts. If some misaligned photos are detected, they can try to be re-aligned or excluded (only if the re-alignment fails). If a relevant number of photos are re-aligned, is highly suggested to repeat the calculations process from the dense cloud generation. Lastly, the final 8 bitmaps (8000x8000 pixels) have been generated using the Adaptive-Orto algorithm, projecting them onto the laser scanner generated mesh (Fig. 14). If the texture calculation fails it's probably due to topology errors in the mesh, thus, all the non-manifold edges, self-intersections, overlapping faces or vertices must be corrected, a lot of applications can absolve this need with automatic procedures, such as Geomagic, Rapidform, Meshmixer. Meshmixer has been also used to correct the inconsistencies between the mesh obtained from the laser scanning campaign and the mesh obtained from the automatic photogrammetry-based 3D-modelling. The inconsistencies between the meshes were due mostly to the fact that the laser scanning campaign was performed much earlier compared to the photographic, and in between the restauration of the Gallery took place, thus some object in the room were moved. The mesh obtained from the photographic campaign was more precise for what concerns the actual configuration of the Gallery, but at the same time the metrical precision was lower compared to the mesh obtained from laser scanning. Therefore, it has been chosen to use the laser scanned mesh as reference base, and stitch to it the correct pieces cut from the Photo-modelled mesh. The cutting and stitching phase was performed only after the meshes alignment. The base mesh was cut in correspondence of the new pieces trying to keep the meshes boundaries as close as possible to facilitate the vertices merging which would be performed right after. Once merged the meshes in one single mesh, it has been geometrically analyzed again and all the topology errors has been repaired using the specific mesh-repairing tools. After successfully applied the photographic texture onto the mesh, the high-definition model has been imported in 3Dmax and it has been elaborated further to generate a low-definition more manageable model, suitable for the video production. It has been chosen to use a less detailed model for the rendering phases to cut the calculation times and to guarantee a faster navigation of the scene during the definition of the camera paths. The model has been globally decimated from 6.000.000 faces to 1.500.000 faces, and it has been further optimized decreasing the number of faces to 750.000, decreasing the number of faces only on the planar surfaces, leaving the corners, the sculptures and the minute details untouched.

7. Stereoscopic video settings

Once finished the 3D-modeling phase, the model has been set up to generate a stereoscopic virtual tour of the Gallery to allow the users to experience it in a full-immersive manner. In the scene they have not been added lights, because the captured textures already contain the light information, thus they only have been placed and animated the cameras along a camera path designed on the basis of a storyboard, and it has been rendered only the "diffuse" pass to avoid the creation of shadows generated by the default illumination of the scene and to cut the rendering time.

The stereoscopy video has been realized with 3Dmax and "Stereo Camera" plug-in with mental ray as rendering engine. The interaxial distance of the two cameras was set to match the standard (Dashwood, 2011; Vatolin, 2011; Woods, Docherty, & Koch, 1993) inter-ocular average value of 65 mm, the two images for the left and right eyes are generated from two cameras with off-axis frustums, the zero-parallax plane has been placed closer to the camera compared to the farthest captured object to increase the perception of distance in the positive parallax space. The right and left eyes frames have been rendered separately, and they have been combined right after using Blender video editor in a Side-By-Side (SbS) compressed .avi video format and lossless .mov format.

8. Conclusion

The low-definition model can be used for static or dynamic visualization and for the animation according to a predefined path that allows the user to enjoy, by various media, a virtual tour of the Gallery in a guided, detailed, complete and full-immersive manner (Figg. 15-17). In particular, the three-dimensional reconstruction and virtual representation of the Gallery is available in stereoscopy, in real time and interactively, through the Virtual Theater 3D. The high-resolution 3D model, instead, is a useful tool for the future conservation and the aesthetic

restoration of the Gallery, to be used remotely and for in-depth studies of historical and artistic nature.

A video-documentary, intended for a wide audience, was also produced with mixed techniques of 3D visualization and video shooting.

It allows a journey through time and in the Gallery accompanied by an original and fascinating background music by Daniele Durante[4]. It is accessible on DVDs and the Internet, through the CEIT website[5], in Italian[6] and English[7].

Through various media (3D virtual theatre, CD-DVD, Internet ...), scholars and enthusiastic tourists will, therefore, be able to admire, even from a distance, the beauty of the Gallery, its architecture full of frescoes and sculptures, to appreciate and study in depth all the historical and artistic aspects of one of the most beautiful rooms of patrician residences in the province of Lecce, a true jewel of Southern art.

The methodology and technology used for the Gallery can be easily replicated for the three-dimensional reconstruction and virtual representation of environments and architectural structures for which interventions are planned both for study and restoration and in order to spread their knowledge for cultural and tourist purposes.

The video-documentary "*La Gallery del Castello dei Castromediano. Ricostruzione tridimensionale e rappresentazione virtuale*" – "*The Gallery of the Castromediano's Castle. Three-dimensional reconstruction and virtual representation*", realized by Virginia Valzano, was ranked the first nationally in the e-Culture & Tourism category of the Italian eContent Award 2014, and represented Italy at international level at the World Summit Award 2015.

The product has been awarded for the best cultural content in digital format, for scientific rigor, innovative methodology and technology applications[8].

The three-dimensional reconstruction project and virtual representation of the Gallery of the Ducal Palace in Cavallino, initiated and coordinated by V. Valzano, required a variety of professional skills and highly specialized skills. The project was carried out with the financial contribution of the Municipality of Cavallino (LE)[9], partner of CEIT, and with the collaboration of other partners, including the Department of Mathematics and Physics of the University of Salento[10], IBAM-CNR[11] and the Department of Architecture of the University of Bologna[12].

Figure 15: one single frame extracted from the stereoscopic virtual tour (SbS .avi format)

[4] D. Durante, Teacher of music education and ethnomusicology at the Musical Conservatory of Lecce; founder, along with Rina Durante, of Canzoniere Grecanico Salentino; artistic director of the Night of Taranta.

[5] CEIT: http://www.ceit-otranto.it ; http://www.ceit-otranto.it/index.php/progetti/78-galleria-palazzo-ducale-cavallino; http://www.ceit-otranto.it/index.php/progetti/241-the-gallery.

[6] Video-documentary in Italian: http://www.ceit-otranto.it/video-files/galleria_cavallino/index_ita.html

[7] Video-documentary in English: http://www.ceit-otranto.it/video-files/galleria_cavallino/index.html

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ITA zip: http://www.ceit-otranto.it/video-files/galleria_cavallino/galleria_castello_castromediano_ita.zip;
ENG mov: http://www.ceit-otranto.it/video-files/galleria_cavallino/gallery_castromediano_castle_eng.mov ;
ENG zip: http://www.ceit-otranto.it/video-files/galleria_cavallino/gallery_castromediano_castle_eng.zip

[8] eContent Award Italy 2014: http://www.ceit-otranto.it/index.php/progetti/78-galleria-palazzo-ducale-cavallino; http://www.ceit-otranto.it/index.php/progetti/241-the-gallery

[9] Cavallino (LE), Italy: http://www.comune.cavallino.le.it

[10] Dipartimento di Matematica e Fisica "Ennio De Giorgi", Università del Salento, Italy:
< https://www.matfis.unisalento.it/home_page >

[11] IBAM - Istituto per i Beni Archeologici e Monumentali del CNR: https://www.cnr.it/it/istituto/006/istituto-per-i-beni-archeologici-e-monumentali-ibam; F. Gabellone, ITLab - Information Technologies Lab, Lecce (Italy): http://itlab.ibam.cnr.it

[12] DA - Dipartimento di Architettura, Università di Bologna (Italy): http://www.da.unibo.it/it .

Fig. 16: Rendering of 3D Model Textured, The Gallery, south side.

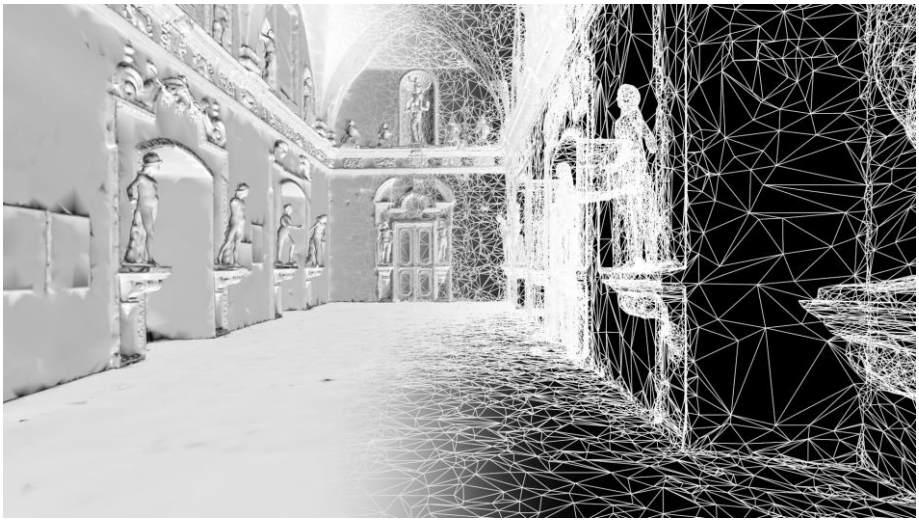

Fig. 17: Rendering of 3D Model flat shaded and wireframe, The Gallery, north side .

Fig. 18: Rendering of 3D Model Wireframe and Textured, a detail of the vault

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