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THE SURVEY OF VILLA REALE IN MONZA:INNOVATIVE TECHNIQUES USED FOR THE VAULTS.

Introduction

Villa Reale (Royal Villa) at Monza has been a study case of topographic, photogrammetric and laser scanner survey for past few years with an aim to describe the complex in its detail and at different level of detail. The project of this important construction was developed by Giuseppe Piermarini, a famous architect known as "*imperial regio architetto*", also the author of *Villa Ducale* and famous theatre *La Scala* in Milan. The villa therefore represents a significant monument for the city of Monza and for Italy since it was also a countryside residence of the royal family. In 1777 the empress of Vienna, Maria Teresa, signs the document that allows Piermarini to begin the constructions of a residence inspired by the famous ones such as Schönnbrun or Versailles. (Fig. 1)

Between 1806 and 1808 the Park in front of the Villa, that today is the largest fenced park in Europe, becomes the property of the Villa's inhabitants. The Villa Reale was also a home of the second king of Italy, Umberto I, while his son Vittorio Emanuele III (married to Jelena Savojska, daughter of king Nikola of Montenegro), refused to use it after his father was shot to death, in 1900. The Villa soon becomes forgotten and starts to deteriorate.

The recent intervention commissioned by Lombardy region[1] for the protection, valorisation and future management of an important monument such as Villa Reale at Monza, were programmed and scheduled as follows:

1. topographic and photogrammetric survey;
2. geometric, material and degradation survey;

[1] Today the monument is administrated by the municipalities of Milan and Monza. In 2003 the Lombardia Region and Monza town have organized a competition for a restoration project. Together with it, the topographic, geometric and the survey of materials and decay survey was needed. The group e-lab (supervised by prof. Brumana e prof. Monti) has participated at these surveys using both the traditional and innovative survey techniques taking a step further in presentation of the objects and generating virtual 3D realities of the rooms of Villa.

Fig. 1 *Villa Reale di Monza*, scenic view

Сл. 1 *Villa Reale di Monza*, пејзаж

3. the theodolite survey of the whole area.[2]

The survey of the villa was an important experience because it helped to develop methodologies of survey for different architectonical elements, in particular environment or in particularly difficult conditions, thus modifying the approaches of survey. The whole practice begun creating a frame network and then getting closer to the building and to greater detail in order to describe the internal rooms and define the horizontal and vertical profiles. The entire survey was done with the purpose of representing the villa and all its elements, leading to the recognition of the geometrical figures that these elements were composed of. The further comprehension of the construction and of the function of various elements made it easier to define different processes of measurements and surveys but also to consider innovative techniques (modern laser scanner instruments, photogrammetric techniques using digital cameras at high resolution) and the great opportunity they offer.

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2 This is the list of the material produced over the last three years of the survey

- digital rectified images in 1:50 scale, ca. 20 000 msq;
- ca. 1000 shots, total amount of 50GB in TIFF non compressed format;
- numerous graphic works (30MB for smaller facades, 1,2 GB for longer ones; for greater facades the images were produced at different resolutions in order to facilitate the data usage;
- horizontal profiles, ca. 1400 m, 25 vertical profiles, around 12 000 topographic points for the total amount of 335 rooms covered surveyed.

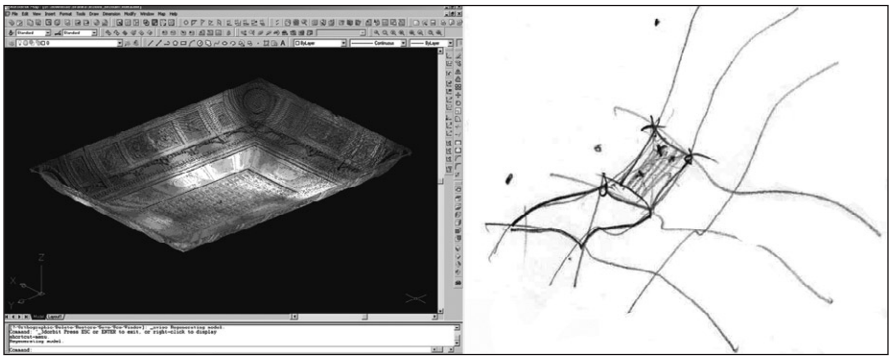

Fig. 2 Cloud points of a the *Sala degli Arazz*i vault observed “from above”; a sketch of an infinitesimally small element re-projected on a three-dimensional model.

Сл. 2 Засенчени врхови на луку *Sala degli Arazz*i гледано одозго; скица једног бескрајно малог елемента ре-пројектована на тродимензионални модел.

This paper, in particular has an aim to describe the approaches on orthophoto generation for the vault elements of Villa Reale. The first one is the traditional approach of matching for Digital Surface Model (DSM), while the second one uses data obtained from laser scanner.

Data roto-translation

The two main products of photogrammetry are rectified images used for mostly planar objects, (so-called “bi-dimensional” object such as walls or pavements) and orthophotos for “three-dimensional” objects or objects that have the third dimension well distinguished (in architecture vaults, apses etc.). An orthophoto is not a projection on a plane such as the rectified image but it is an orthogonal projection obtained by rectifying infinitely small parts of the shots that are locally considered plane and re-projecting them on a three-dimensional altimetric reference model.

In terrestrial photogrammetry often are used the same commercial software as in aerial photogrammetry. Therefore, the process of data acquisition and that of orthophoto construction are very similar. This means that the observed surface, whether it is a floor, a vault or a wall, is always treated as the ground is treated in aerial photogrammetry. Hence, the third dimension (z coordinates) should always be going into the photogrammetric camera. This leads to all the coordination systems of different surveys used being adapted to the system of the photogrammetric reference.

In particular in the cases of vaults this means that the whole system of reference should be rotated in order to observe the vault “from above” as a sort of a concave terrain surface. Hence, the topographic Ground Control Points (GCPs) taken should undergo a process of translation and rotation so that the coordinates should be in a correct reference system (see Figure 2).

This also occurs for the points of laser scanner cloud: after the scanning and the different clouds unification, every element (wall, floor, vault) should be

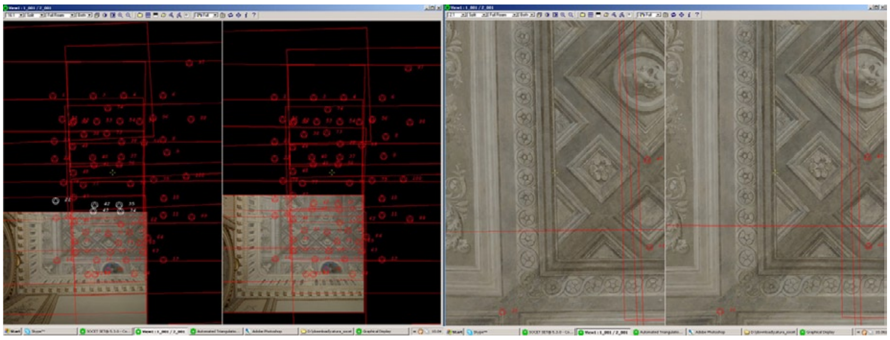

Fig. 3. A photogrammetric block of 14 immages; example of a non - rectified and a rectified image.

Сл. 3. Фотограметрички блок од 14 слика; пример не-пречишћене и пречишћене слике.

isolated and treated separately in a local coordinate system. As for GCPs, they are again roto-translated and adapted to the previously described main coordinate system. The final product, a rectified image or an orthophoto, will have its local coordinate system.

Traditional approach using matching process

As an example of this method, we propose the survey of the vault of *Sala degli Arazzi (Tapestry Room)*. A block of 14 photogrammetric shots[3] has been used, with all the shots taken taking into account the laws of stereoscopy.

The frames are firstly singularly oriented and then connected between them using the method of aerotriangulation bundle adjustment, based on the determination of image coordinates, GCPs' (Ground Control Points – topographic points) and TPs' (Tie Points) coordinates (sw Socet Set).

In this particular case 100 points were collected topographically, while TPs were calculated automatically and then checked manually one by one. Once the orientation is done, every shot is re-projected on DSM/DEM generated by software using the matching process (Figure 3). The orthophoto obtained has a precision of a scale 1:50, a high precision architectonical scale for restoration and conservation purposes.

As said before, in order to create an orthophoto the DSM/DEM of the object is needed. Traditionally, in aerial photogrammetry digital model is obtained by the autocorrelation process using an automatic mode.

Photogrammetric software can produce two types of files, an image file and a georeferencing file (in this case a TIFF and TFW). This means that the

[3] Photogrammes are taken with camera Rollei db44 Metric (CCD PhaseOne H20 4080 x 4076 - 16 MegaPixel; pixel dimension 9µm; sensor dimension 36.9 x 36.9mm and CCD PhaseOne P45 7228 x 5428 – 39.2 MegaPixel; pixel dimension 6.8µm; sensor dimension 49.1 x 36.9mm; objectives used: 40mm; 80mm; 150mm; calibration for every objective).

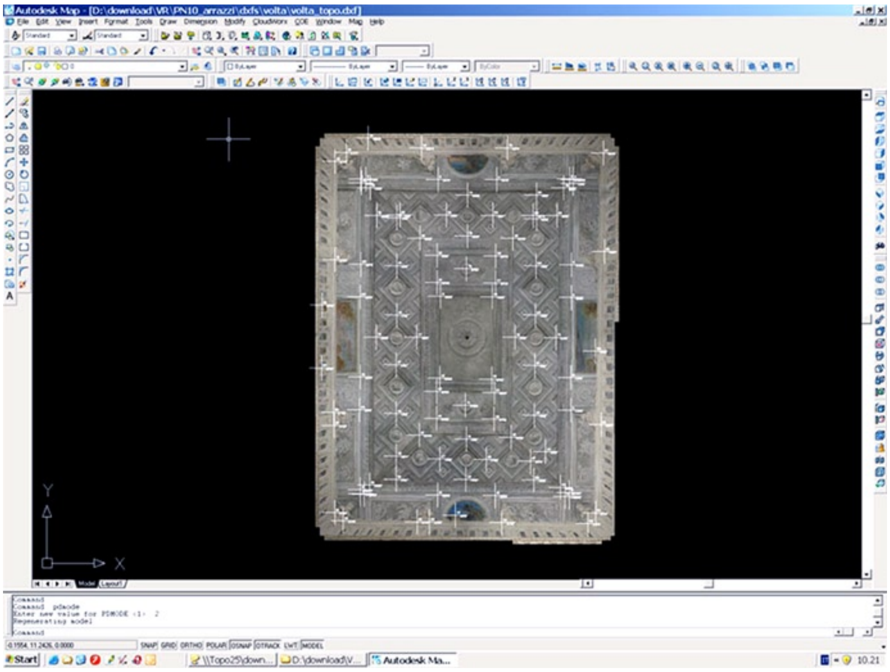

Fig. 4. An orthophoto of a vault in a CAD environment overlapping its GCPs.

Сл. 4. Ортофотографија лука у ЦАД окружењу која се преклапа са својим ГЦП

image can be inserted in a Cad working ambient and compared to the initial coordinates of the Ground Control points. The Figure 4 shows an image of the orthophoto of *Sala degli Arrazzi* with the overlap of the topographic points; the accuracy scale of the printed product is 1:50 but the detail on monitor also fulfils the accuracy of larger scales, 1:20, 1:10.

While in aerial photogrammetry the product generated with the method of autocorrelation process is acceptable, since it is permitted by the precision of the scale requested (1:1000, 1.2000). For the survey of cultural heritage, on the other hand, a higher precision scale is required (1:50, 1:20). Therefore the Digital Elevation Model should also be of a very high precision describing the object in great detail.

This aim could be achieved by increasing the value of the ground pixel (i.e. moving closer to the object of survey) but it would also mean having more problems during the fieldwork (specifically in case of ceilings that are sometimes few meters high), many more single shots to orientate and unite into a photogrammetric blocks, and therefore a more complex procedure that would take more time.

Another approach experimented was the use of the three-dimensional model generated by the point clouds of laser scanner as a surface for the photogrammetric block projection.

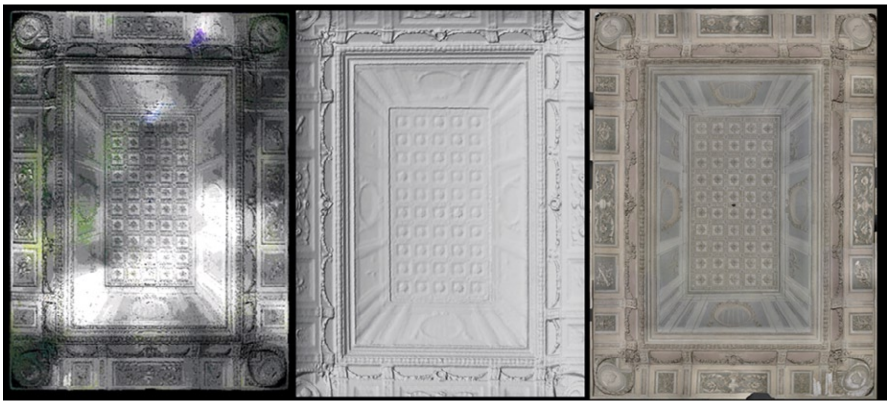

Fig. 5. Sala della Pendola vault: cloud points; solid model; orthophoto.

Сл. 5. Лук Sala della Pendola: засечени врхови; чврст модел; ортофотографија.

Laser scanner and innovative techniques

The vaults of *Villa Reale* of Monza were particularly interesting object of study because all of them have numerous stucco decorations. These characteristics required a high precision surveying scale in order to produce orthophotos at scale 1:50 or 1:20 that would serve to experts during conservation and restoration processes.

In order to obtain products of a high precision scale, an innovative technique of usage of laser scanner[4] data has been experimented. All rooms of the *Villa Reale* were scanned using one or two scanning stations (depending on the room dimension) and the clouds were then separated into single elements (walls and vaults) in order to create a 3D model support. This is possible given the properties of the instrument used. The study case chosen for the illustration of this method is the vault of *Sala della Pendola (Room of the Pendulum clock)*.

As said before, the cloud points of the vault were roto-translated in order to have the z-axis coming towards the observer. The same procedure was followed as before: in this case six shots stereoscopically taken were used to create the photogrammetric block and their bundle adjustment was done. Instead of generating the Digital Elevation Model automatically, a surface model obtained from cloud points that approximates the surface of the real object to a great level of detail was used (Figure 5). In fact, the commercial photogrammetric software allows an external DEM to be inserted but it has to be converted to the type of file supported by the software chosen. In this case it was possible to use the point clouds of laser scanner but with certain modifications. First of all, the files containing scanning data are usually very "heavy" (ex. *Sala degli Arazzi*

[4] Brief characteristics of Leica HDS3000: maximum visual field of 360°x270°, double scanning window; visual field and scanning density entirely selectable; digital camera integrated; precision measurement of 4mm at a distance between 0m and 50m; measurements of instrument height; station on the known coordinates; current supply flexible, substitutable during functioning; scan row maximum: 20,000 points/row e 5,000 points/column.

Fig. 6. Virtual model of a room with photogrammetric images used as textures.

Сл 6. Виртуелни модел просторије са фотограметричким сликама коришћеним као текстуре.

140MB, *Sala della Pendola* 106 MB) and hard to manage, so they need to be "filtered" i.e. decimated maintaining their initial properties in order to be used[5]. This is the phase called *pre-processing*. While the cloud points are the raw products of laser scanning operation and they need only filtration, for the surface generation data are processed and elaborated with modelling software such as RapidFormXO or RapidForm2006. At this point it is necessary to *determine the global topology of the object's surface* in order to preserve its main and particular features and edges by a process of a virtual decomposing of the object into more simple geometric units. After an appropriate decimation, a Triangulated Irregular Network surface is created and consecutively modelled during a step called *generation of a polygonal surface.* This surface is composed of infinitely small triangles produced by connecting the closest points of the laser point cloud in a network. An ultimate step of *post-processing* is then commonly performed in order to edit, refine and correct the generated polygonal surface.

In the case of *Sala della Pendola* a cloud point was used and as explained above the oriented images were re-projected on this digital model in order to generate a high precision orthophoto as shown in figure below. The product generated has a very high image quality level and although the survey was done for a restitution scale 1:50 (the number of shots taken, the distances considered etc.), it can be printed out at higher scale such as 1:20.

[5] The photogrammetric software used during Sala della Pendola data elaboration is PCI Geomatica – module OrthoEngine excepts DEM in different formats such as point clouds, 3Dlines, surfaces, etc.

New methods of representation

Virtual museums as a way of data consulting is extending its application in various fields and is becoming dedicated to various user groups such as visitors, architecture, art or archaeology students but also professionals and scientists.

Both of the products described above are orthogonal projections of three-dimensional objects and they can be both visualised in Cad Workspaces and printed but only as two dimensional products. In order to visualise them or use them for measurements in three-dimensional space it is necessary to re-project them on a model in a workspace such as Autodesk3dS Max. Since all images are georeferenced, they can be inserted into previously constructed virtual model in their exact spatial position. In this way all types of measurements such as distances, areas and volumes can be done in the virtual space. (fig. 6)

This opportunity is very valuable in particular for the restoration purposes, in order to calculate the amount of deteriorated material or elements and the possible quantity of those ones to be substituted. The possibility to explore virtual environments allows different spaces to be visited and discovered even when the access to the real ones is not permitted for the restoration motives or other reason providing a wide range of opportunities for virtual reality spaces such as e-Portals and virtual museums.

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ПРЕМЕРАВАЊЕ ВИЛЕ РЕАЛЕ У МОНЦИ:ИНОВАТИВНЕ ТЕХНИКЕ КОЈЕ СУ КОРИШЋЕНЕ ЗА ЛУКОВЕ

Вила „Reale di Monza“ (Краљевска вила у Монци), у току протеклих пет година, била је предмет студије за топографско, фотограметрично и мерење ласерским скенером са циљем да се овај комлекс опише до детаља и у различитим размерама. На само мерење увек утиче коначни циљ због кога се мерење врши, чињеница која је у овом случају довела до одређених разматрања.

Посебо, и у овом раду биће илустрована два метода ортографије конструкције орнамената на луковима Виле: први је традиционални приступ који користи методу

процеса ауто-корелације за генерацију дигиталног модела. То је аутомацки процес који обавља фотограметични софтвер онда када су убачени сви подаци на ваздушну триангулацију, да би систем функционисао. У том случају ДСМ (дигитални површиски модел) мрежу одређује оператер у складу са величином земљишта у пикселима.

Са друге стране, експериментисало се са методом ласерског скенирања. Ово је мање аутомацки процес и подељен је на неколико фаза. Врши се екстраполација (изводе се вредности) података добијених процесом ласерског скенирања (засенчени врхови), филтрирају се и моделирају да би се користили као подршка за ДСМ генерацију. У овом случају, настала ДСМ мрежа зависи од резолуције и од прецизности скенирања. Пошто су лукови Виле Реале били веома богати орнаментима и украсима у гипсаном малтеру, овај приступ омогућио је да се ради у различитим блиским оквирима и да се добије боља дефиниција неких делова лукова који су захтевали снимање изблиза, или детаљнији опис. Последња фаза пројекта сагледава 3Д виртуелну стварност где различити корисници могу консултовати и користити све продукте фотограметричног мерења и мерења ласерским скенером.