

THE FACADES OF GOTHIC BUILDINGS IN VENICE: SURVEYS VERIFYING CONSTRUCTION THEORIES

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ABSTRACT

The façades of numerous Gothic-era buildings in Venice, especially those that overlook the Grand Canal, display the tendency to demonstrate a substantial degree of “*entropiombo*”. In other words, the structure is not quite a vertical plane but rather tends toward a slightly sloped surface. Presently, this phenomenon is the subject of analysis and study by historians and restorers which have found the slope to be a "design" choice and are attempting to identify the construction traditions of the times, rather than the "rules" of construction. The slope of the façade (assumed to be a design decision) might have been necessary to the special systems of connection between the vertical and horizontal elements, the arrangement of the floor slabs or the type of foundation. This theorized warping “by design” is accentuated by other warping due to subsidence and settling, localized or general, of the buildings which are always displayed in Venetian structures. The result is a complex geometric configuration which is quite difficult to read. Today, the availability of laser-scanner instruments has made it possible to reduce the acquisition times of the data and automate extraction of the profiles, but most importantly, such instruments have made it possible to create a descriptive 3D model of the surface. As a result, a research campaign was launched, sponsored by IUAV, which includes an identification and test of the survey methods and representation for a comprehensive study of the warping phenomena displayed by Venetian façades. The paper describes the survey methodology used in the research (topographic support, laser-scanning, photoplanes and orthophotos) and the representations that have been formulated to describe the structural surface (models of warping). Several cases are illustrated as examples of the work conducted.

INTRODUCTION

The Photogrammetry laboratory at CIRCE is conducting a research campaign to identify a procedure for survey and representation of warping on the façades of Gothic-era Venetian buildings. With respect to an ideal plane, the warpings can be caused by two different sources: the first, the object of this research, involves a hypothesized “*entropiombo*” of design, in other words, a deliberate slope of the plane of the facade inward. The reason behind this seems to be the construction technique used in these buildings: in the local construction culture, the walls of the façade were not anchored to the masonry framework. This hypothesized design warping is added to the second reason, represented by the warpings due to subsidence and settling, either local or generalized, of the buildings which always appear in Venetian structures. The result is a complex geometric configuration which is quite difficult to read. The studies conducted till now have resulted in very important observations relating to the individual cases, but a comprehensive investigation has not been done on a statistically consistent sample of façades, which could help identify construction "customs". To date, the geometric analyses have been based on a model of the warpings achieved by a substantial number of vertical and horizontal profiles, selected in the most relevant areas of the façade. Survey by topography or photogrammetry proved to require an inordinate amount of resources, which is why the investigations have always involved a fairly limited number of buildings.

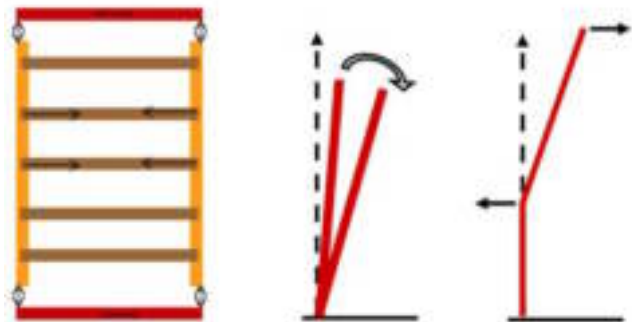


Figure 1. Scheme of the construction techniques of gothic façades and movement hypothesis of venetian buildings.

Thus, the research team launched a study entitled "Organization of the knowledge and diagnostics for conservation of the historic Venetian building tradition" (CORILA research programme), financed by the IUAV which entails that the CIRCE photogrammetry laboratory identify and test the methods of survey and representation for a widespread representation of the warping phenomena of the Venetian façades in the study.



Figure 2. Some buildings localization on Venice map

A series of historic buildings located in the lagoon city were identified as exemplifying the construction characteristics studied and, as a result, would be able to provide important case studies for carrying out the research.

1. SURVEY METHODS

Each façade was surveyed using several methods (topographic, laser scanning), in order to provide a comparison and obtain a correspondence between the data obtained in each survey and between the printouts obtained, in consideration of the purpose for which the survey is carried out and who the final users of the survey will be. The team commenced with a preliminary topographic campaign using a Leica TCRM total station to acquire the control points for building photoplanes and detail points for rectification of horizontal and vertical profiles. These were appropriately chosen in relation to critical areas for precisely identifying the *entropiombo* and further warping due to subsidence and settling. The topographic survey also provides the fundamental definition of the reference system which is the basis for all the observations made, in addition to the support to the laser scanning survey. Since the planimetric position of the façade can be indifferent, it becomes essential to define the absolute quota with respect to which the altimetrically defined phenomena of deformation are analyzed. Therefore, the reference system is local in X and Y for each building, while the Z always refers to the national system of levelling survey stations.

A second phase focused on laser scanning survey. The instrument used was the Riegl LMS-Z320 laser scanner whose technical characteristics make it possible to define the maximum measurement uncertainties of acceptable tolerance for an architectonic scale (1:50). It is well known that because this instrument is integrated by a high resolution digital reflex photocamera with calibrated lens (the camera is mounted on a D100 Nikon camera with a 200mm lens), scans the point cloud in addition to the digital images which are calibrated in the scanning system. Therefore, the geometric contents are supplemented by the descriptive data of the RGB of the points. By integrating photogrammetry and laser scanning, the system represents one of the best technical solutions available today that can meet all the needs of terrestrial laser scanner survey. The façades of buildings selected normally demonstrate linear

geometries, with limited decorative additions, interrupted here and there by projecting balconies. Frequently, however, the conditions are not ideal for setting up the scanning instruments as the working conditions are rarely spacious and unobstructed. The need to have a uniform density of points and to record the overhangs and protrusions requires an increased number of the scanners depending on the height of the façades; frequently, the instrument had to be positioned an inclined axis.



Figure 3. Instrumental verticality is fundamental in a façade control survey to avoid errors in profiles extraction

One of the biggest disturbances was the presence of obstructions on the façades: the presence of flowers and plants on the window sills or balconies and open shutters create several shadow areas. Precisely because of its most important characteristic - providing a dense model for points of the entire surface -this method is much better suited to the purpose of obtaining horizontal and vertical profiles not necessarily identified in the acquisition phase of the campaign. Extraction of the profiles is deferred to a later time and does not necessarily have to be done by the survey technician, but can be done by professionals in other related sectors (restorers, structural engineers), thereby obtaining more specific information compared with the geometric and structural analyses that will be conducted. It becomes essential the registration of clouds. We are normally used to considering at least three methods:

1. geo-referencing the clouds on topographic points: this consists in a roto-translation in space (six parameters: 3 translations and 3 rotations) of every cloud in the topographic reference system. In short, the operating phases are:
 - recognition of the homologous points on the individual clouds and on a topographic points list;
 - roto-translation of every cloud in the topographic system;
 - clouds merging;
2. cloud on cloud: roto-translation of a cloud in the system inside of another. With this method, there is no external reference system but one attributes the role of global reference system to the system inside a cloud. The operating phases include:
 - automatic recognition of the tie points on the clouds;
 - roto-translation of every cloud in the "reference cloud" system;
 - clouds merging;

If targets are not used for automatic recognition, registration of the points calls for a manual intervention in selection of the homologous points. The global alignment comes about through matching algorithms (fuzzy join and ICP iterative

closest point), and therefore, requires a larger extension of the overlapping area between the scanings in order to improve and facilitate registration.

3. spatial triangulation: it makes reference to aerial triangulation for independent models. It is the sum total of the two previous methods using both tie points and control points, guaranteeing exceptional control and minimizing the number of points surveyed topographically. The operating phases are:
 - recognition of the tie points on the clouds;
 - identification of control points
 - simultaneous estimate of the parameters of roto-translation of each cloud
 - roto-translation of each cloud in the global system;
 - clouds merging.

It seems clear that in this study, the definition of the vertical axis is of primary importance. As a verification of the methods of registration, we applied both the "cloud on cloud" method on one of the buildings with automatic recognition of the targets and the method based on spatial triangulation.

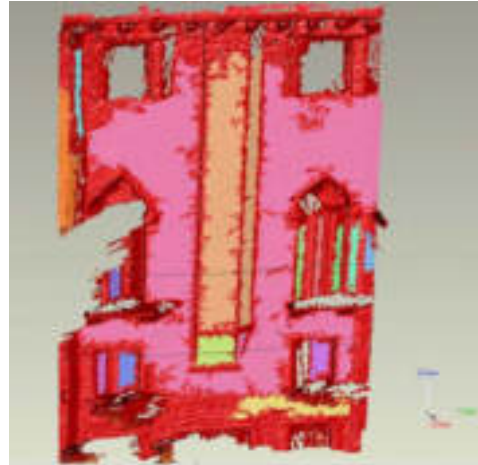


Figure 4. Detecting planes operation: detects regions where enough mathematical criteria are met to indicate that a plane exists



Figure 5. Growing error in orthophoto due to errors in vertical axis definition

While obtaining satisfactory results from the analytical geometric perspective in both methods (sqm range from 0.4cm to 1cm) in realizing the orthophoto of the façade, therefore with the intermediate phase of an orthogonal projection on the vertical plane of the building, we obtained a growing error compared with the vertical axis, reaching up to 20 cm in the larger distances. It is clear that in this situation, the most appropriate approach to take is spatial triangulation.

2. PROCESSING THE DATA

2.1 Profiles

Considering the objects of study and their problems, integration of the methodologies has made it possible to obtain more extensive processing of the data, in the sense that the types of digital products that can be rectified are greater and therefore obtain an accurate documentation of the state of fact of the buildings through profiles, elevations, and orthophotos.

We also followed the classic procedures for photogrammetric

and topographic survey in the rectification processes, while the laser scanner data - after preliminary handling -were processed using new commercial software (RiScan, Rapidform, Geomagic) and other non commercial packages (Laser Scanner Registration of the Polytechnic of Turin) which are capable of handling a large number of points. As is typical in survey procedures, the main difficulties can be found clearly by the complexity of the architecture (but in the case in this study, the geometry was simplified in a favour of static reading), from the place where the buildings were inserted (the urban spaces are often quite tight and as a result, it is impossible to have an optimal geometric outline of acquisition) and the obstacles that have provoked a further noise especially in the laser scanner data. For each façade, a reference system of XY axes was set up, diagonal to the average progress of the façade, and a vertical Z axis (topographic). The topographical data and the laser scanning points were geo-referenced in accordance with this system.

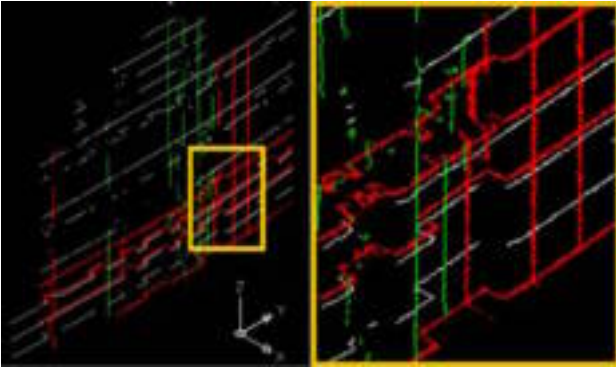


Figure 6. Rough profiles obtained from scanning

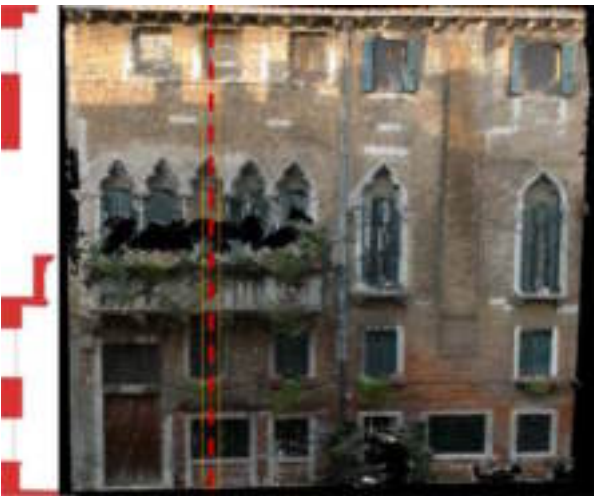


Figure 7. Edited profile

The first product processed is the description of the architectonic surface by means of a series of vertical and horizontal profiles extracted from the point cloud, extracted automatically and compared, where a correspondence is found, with the ones surveyed topographically to ensure the accuracy and congruence in describing the building. This does not result in a finished product, but several polylines that are still influenced by noise and errors in alignment of the clouds. These early segments must be therefore interpolated and partly edited to obtain the description of the façade in a form that meets the representational regulations of architecture.

2.2 Rectification

While not significant in the study of the profiles, photogrammetric rectification is the preliminary basis on which to chart several phenomena that involve the state of conservation of a building: overall fissure pattern, decay of the materials. In the case of the studied buildings, each façade was rectified by segments, in consideration of the fact that it would have been impossible to describe on a single plane. It's obtained a sort of development with respect to the vertical plane. The rectifications, inserted into the local reference system of each survey, are saved in the Ermapper .ecw format to maintain the original resolution (1 pixel=0.004m) while compressing the image and, thanks to a special viewer, obtain a rapid metric consultation specifically for altimetric data.



Figure 8. Rectification and development respect different planes



Figure 9. Raw orthophoto

2.3 Orthophoto

The term true orthophoto signifies a product where even the perspective warpings that do not belong to the surveyed surface are corrected. To produce precision orthophotos, we need to have DEM that take into due consideration the many altimetric discontinuities detected.

In some cases, the classic photogrammetric method entails information processing for which the orthoprojection achieves unacceptable times and costs, while with the arrival of the laser scanner, the procedure using DEM has gained in importance. Furthermore, by using several images, we can obtain a comprehensive description that is not marred by shadow zone on the element being studied. It is also important to consider that in the phase immediately after scanning, the management software of the Riegl instrument (RiScan beta-version 1.1.2B29)

makes it possible to create a preliminary "raw" orthophoto directly from the point cloud and from the images calibrated and corrected by the distortion of the objective. In this way, we can obtain a geometrically correct raster representation in an orthogonal projection to use to make a geometric description of the façade: while still demonstrating shadow zone and other inaccuracy especially near the edges, the orthophoto can be digitalized to obtain a vectorial representation of the façade.

2.4 Digital Surface Model

Therefore, we have to start with the point cloud to generate a surface model that can guarantee the descriptive continuity of the structure of the building, highlighting any lack of verticality. The data are gridded on a regular step (0.05x 0.05m) eliminating in the interpolation the data that could contaminate the model. By introducing faults, we have eliminated from the calculation process the points in correspondence to the doors and windows, where the presence of glazing, windows and balconies with flowers lead to another noises to the precision of the model. A fault is a two-dimensional blanking file defining a line acting as a barrier to information flow when gridding. When gridding a data-set, data on one side of a fault is not directly used when calculating grid node values on the other side of the fault. The method used is *kriging*, which has proven useful and popular in many fields. *Kriging* is a very flexible gridding method that can be custom-fit to a data set by specifying the appropriate variogram model. *Kriging* can be either an exact or a smoothing interpolator according to user-specified parameters. The grid was interpolated starting with the raw laser scanner data and with the filtered data to reduce the effects of noise. The difference that has highlighted the effects of uncertainty of the tool used and the registration of clouds ($\pm 2.5\text{cm}$) was made on both grids. Considering that in this model, the study was concentrated on the structural part and not the decorative part, the DSM was filtered with a low-pass filter to remove the high frequency noise with the resulting output being a smoother grid. The model obtained in this way can subsequently be exported into surface modelling software (such as Geomegic, Rapidform, Maya). The next step is to achieve a 3D orthophoto that links the contents of the previous products (orthophoto and DSM) and represents a maximally descriptive model that can be very useful as a basic instrument for architecture analysis.

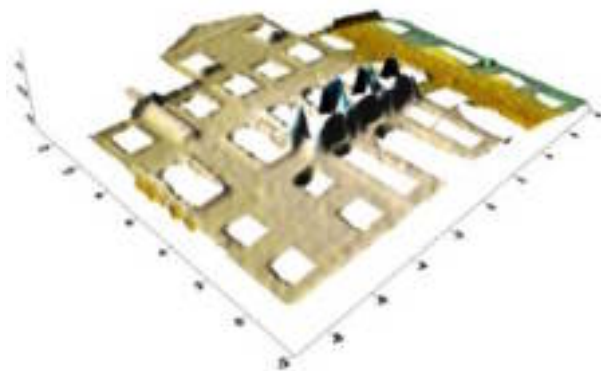


Figure 10. 3D surface of a interpolated grid filtered with low pass filter

3. LASER SCANNING IN TEACHING

The experience accrued in architecture survey using the laser-

scanner has demonstrated that this instrument and the techniques for processing the data that it produces are not alternatives to photogrammetric and topographic survey nor can they replace such techniques. Some of the products that can be obtained with the laserscanner, as we have seen in this last experience, lend themselves very well to use in the field of teaching, which frequently calls for large numbers of surveys and 3D data processing. University laboratories are increasingly being asked to provide surveys of structures which are then studied as part of courses, in thesis, or during research campaigns. As an alternative to university technicians conducting such surveys, the trend has been to launch experiments that seek to provide students and researchers with "semi-finished" products of survey, from which the users can gather metrical information that is useful in realizing the survey elaborations they need. What's more, the final plotting is done by a new author: where once this phase was the domain of the photogrammetry expert or topographer, the final user can now take over. The latter has the opportunity to measure and represent what he believes is essential to his work without the need for specific expert skills. The survey of gothic facades is an interesting field of applications to test the possibilities given by laser scanner survey in teaching .



Figure 11. Scan of a venetian square



Figure 12. Detail of point cloud



Figure 13. Comparison by overimposition of a photogrammetric rectification and a laser scanner ortophoto

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