Integration of traditional and innovative techniques to resolve a complex case: Monitoring the movement and temperature influence of the canvas in the south transept of the Church of the Convent of San Luis in San Vicente de la Barquera (Cantabria)

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1. Introduction

The former Convent of San Luis in San Vicente de la Barquera is dated in 1454, according to existing literature, although it was remodeled during the late fifteenth and early sixteenth century. Currently there are remains of its original structure such as vaulted covers of the apse, choir and the north and south facades. The rest of the cover of the nave collapsed many years ago. Despite the enormous damage to the structure meant the disappearance of the entire deck with its arches, vaults and cover material, the remains were kept in fairly good condition.

The collapse of the arches of the cruise ship, eliminated strike the balance between the thrusts of the arches and the countermeasures of the buttresses, but left a canvas to 12.00 m. of height and unable to balance effectively the horizontal actions as the wind pushes.

The same can be said with regard to turns that might try to take the façade as a result of the action of eccentric loads on a plot of foundations whose geotechnical feature allowed certain seats.

The main pathology observed in this construction, is caused as consequence of the previous things, and manifests as a crash towards the interior of the transept, the south facade. This crash course it is irregular along the facade. The largest corresponds to points near the choir.

2. Objective

Consolidation of foundation and buttresses and the masonry of the canvas of the south facade by means of the most appropriate techniques that can ensure the future right behaviour of them.

3. Constructive Solution

The works included tasks related with the terrain, with buttresses and the temporary stabilization of the facade, according to the following sequence:

(a) execution of the micropiles of the provisional stabilizers of the façade;
(b) installation of stabilizers;
(c) preparation of consolidation in the ground under the baseboards-foundations of the south façade;
(d) consolidation of the buttresses by injecting inside of micromortars-micro-
cements through polyethylene pipe in drills;
(e) execution of liabilities anchors in the rock exterior buttresses.

4. Technological Solution
The solution initially proposed the implementation of a topo-geodesic auscultation network that integrate laser 3d scanner data observations. This network materialised by trademarks and observed through total station, had a double objective, referenced the rest of observations and control movement between Miami.

The integration of laser scanner data allow an exhaustive control of the movements of the canvas. 18 campaigns were conducted during morning hours (8:00) or afternoon (13:30), between February and June 2012. After several campaigns of auscultation, appreciated chaotic movements between campaigns and some dependence between observable according to schedule were made.

The canvans suffers from overheating due to the Sun throughout the day on both sides since the canvas is outdoors which leads to a movement of the same. This parameter (temperature of the canvas) was initially not taken into account, but the observations made hinted its influence.

This article shows the methodology and results achieved in integrating traditional data micro-geodesic with laser scanning 3D and thermography in the auscultation of the canvas movements.

The method, in addition to providing a precise geometric control, is used to predict and perform simulations of the positions of collapse according to the temperature of the sides of the canvas.

4.1. Geometry

4.1.1. Reliabilities
It aims to control movement between campaigns of a facing wall. The aim is to achieve overall reliability of the measure of 3 mm. To achieve this, it was decided by a combined method of creating a local network using total station to set the framework and scanning laser 3D scanner for scanning massive wall facings.

In the topographical campaign values were monitored the temperature, pressure and humidity, which might affect the scaling factor as follows:
- TEMPERATURE: Variation 10 °C = 9.9 ppm
- PRESSURE: Variation of 30 mbar = 8.4 ppm
- MOISTURE: Variation of 0-100% = 4 ppm

We used a total station with 2” angular accuracy, a reliability in distance of 1mm +1 ppm, compensator to correct Hz and V angles of the lack of verticality of the station. we adjusted a three sides network because reliability is greater in distance and the holding of six Bessel series perform a miniprism accuracy. The bases were leveled using a digital level, which allowed rings seals better than 1 mm.

The radiation error of the targets used for the georeferencing of the scans is estimated at 1.5 mm, this value is used as the reliability of the bearings in the block adjustment of the scans.
4.1.2 Local Network

First we decided to design, observe and adjust a local network in order to provide data a reference system with good reliability, and in order to control land subsidence or lateral movements of the whole structure.

The network is materialized using phenotype milestones or “geo-punt”. The network, formed by six vertex, was performed using a trilateration, obtained from the average of 6 observations series of forward and reverse, in order to achieve the reliability necessary for monitoring the structure, which should be in the range of 1 mm.

For the calculation as linked network, decided to set two stations, one inside and one outside that corresponded to the stations with the highest number of observations and observable. Fixed stations correspond to the 1 and 3 as shown in Figure later.

Therefore, the network was configured as follows:
- Number of vertex of the network: 6 (2 fixed)
- Total Number of equations 11 (0 condition)

Corrections to offset variables and variables obtained were:

<table>
<thead>
<tr>
<th>Variable</th>
<th>Correction</th>
<th>Variable Offset</th>
<th>Standard deviation</th>
</tr>
</thead>
<tbody>
<tr>
<td>X (2)</td>
<td>-0.001</td>
<td>109.084</td>
<td>0.001</td>
</tr>
<tr>
<td>Y (2)</td>
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<td>0.001</td>
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<tr>
<td>X (4)</td>
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<td>Y (4)</td>
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<td>65.191</td>
<td>0.001</td>
</tr>
<tr>
<td>X (5)</td>
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<td>124.930</td>
<td>0.001</td>
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<tr>
<td>Y (5)</td>
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<td>87.232</td>
<td>0.001</td>
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<tr>
<td>X (6)</td>
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</tr>
<tr>
<td>Y (6)</td>
<td>0.001</td>
<td>104.145</td>
<td>0.001</td>
</tr>
</tbody>
</table>

Scale Factor = 1.02 ppm, with a standard deviation of 0.00001. The estimator of the variance of unit weight observable: 0.00578

Error ellipses are:

4.1.3 Scanning the wall

In each campaign were made nine scans into the building, plus 2 on the ends and 5 on the outside (see figure below in which there are 9 scans and the information used, each scan of a color). For the purposes of this communication, only that the inner wall.

For scanning used a 3D laser scanner with the following features:
In 18 campaigns, the reference frame materialized by 9 points and 3 stations radiated inside the building, which were used as supports in the block adjustment. The correction applied in the calibration block, allowed to obtain coordinates of the scan points with a deviation less than 0.5 mm for all scans in all campaigns. As a test, we added a constraint for shots inclinometer but given the spatial configuration of the references did not help the solution.

### 4.1.4. Initial state of the wall

Prior to the consolidation project, a campaign source or reference for the status of the wall was made. In it, we obtained a series of planes crash and bulging of the wall and was derived a map of crashes canvas, in which each 2x2 cm². There were a distance value to a plane source, adjusted to the wall but constrained to vertical, that is, it follows the line of the plummet.

We implemented an algorithm for calculating normal plane distance between the element created and the contact face.

Fig. 1 - Example information sections with bulging and collapse
4.1.5. Geometric control of the wall

The consolidation of the structure was carried out in five phases over 18 campaigns were undertaken including geometric control. The phases were controlled movements were:

• Phase I: Implementation support micropiling provisional stabilizers of the facade. 7 campaigns were undertaken during this phase, and the results are shown below. Given the reliability of the method, it is set to values less than ± 2 mm are below the detectable threshold and are symbolized by green. The shades between yellow and red, represent points where movement has occurred into the convent, while the range of shades between cyan and navy represent offsets out of the convent. If the canvas did not move, remain entirely in green, but in this case there is a crash increase less than 20 mm at the center left of the wall and gable, while the right has leaded and even shifted slightly toward out.

• Phase II: Installation of scaffolding Outrigger three campaigns were undertaken during this process and basically appreciate stabilization movement that led to the wall aplomase slightly, that is less than 1 cm in the belfry.

(a) Comparison between the campaign 8 and 9, corresponding to the beginning and end of the assembly of scaffolding outriggers; (b) Comparison between the campaign 1 and 7 corresponding to the preceding and following micropiling phase. Both were performed at the same time.
• Phase III: Implementation of consolidation grouting under the baseboards of the foundation of the south façade (or outside). There were 3 seasons. Basically we see a stabilization of the lowlands and flat ends. However outside injection, causes an increase occurs inside crash, whose maximum is 4 cm in the gable area, possibly due to a rotation thereof.

(c) Comparison of the campaign 10 and 11, corresponding to the beginning and end of the consolidation of the foundations of the south facade; (d) Comparison of the campaign 15 and 14, corresponding to the beginning and end of the consolidation of the buttresses

• Phase IV: Consolidation of the buttresses by injecting inside micro-cements through polyethylene tubing inserted into bores. No notable moves are seen during consolidation of the buttresses. The maximum values are due to the filling of the perforations.

• Phase V: Implementation of passive anchors to the rock buttresses. Campaigns were carried out 5 key sunshine hours, ie at sunrise and noon. Simultaneously geometric registration thermographic data were recorded. The purpose was twofold: on the one hand to control the geometry as it had been doing in the consolidation process and the other to measure the influence of the thermal contrast (difference between inner and outer canvas of the building) or movement produced dilation mortar as a result of the heating of the canvases. In the above case shows that the wall remains virtually unchanged, except the belfry area has collapsed just a few millimeters, possibly because the structure did not have enough time to relax. On the other hand, in one hour of greatest thermal contrast shows that the collapse seen as increases to almost 20 mm, even after consolidating the wall.

(e) Comparison between 16 and 17 campaign. Both were recorded before impinging sunlight on the wall (8:00 am); (f) Comparison of the campaign 18 and 16, corresponding to before impinging sunlight on the wall (8:00 am) and past noon (16:00)
4.2. Thermography

Thermographic campaigns were conducted in May, corresponding to the campaigns 14, 15, 16, 17 and 18 geometric controls for the interior and exterior of the wall simultaneously scanning process. The aim was to know, from an average emissivity value for all facing, the temperature inside and outside the canvas in order to quantify, for the time interval scanning thermal contrast of the wall, or temperature difference between the outer and inner wall canvases. To capture data has been used a thermal imager, calibrated to work in the temperature range -20 ° C to 100 ° C and thermal sensitivity <0.05 ° C.

5. Conclusions

The integration of the different techniques used in this work has successfully solved the case raised. It has been shown that the methodology and algorithms developed raised are effective and useful in heritage.

References

Anquela A.B., Chueca M., Berné J.L., 2001, Aportaciones al problema general de redes locales de alta precisión: condicionantes específicos de fijación de criterios teóricos y prácticos, de calificaciones de parámetros intermedios y resultados finales.
Baarda W., 1977, Measures for the accuracy of geodetic network, Sopron.