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Methodology of efficient assessment of structural deformation from Non-intrusive techniques for Civil Heritage conservation.

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ABSTRACT: Cultural Historical Heritage today performs an important role, not only in transmission of social values, but also with important economic contributions. Conservation and in particularly the assessment and monitoring of structural deformations can only be accomplished through efficient management. In today's society, which is not feasible from an economic point of view cannot be sustained along the time, on that line the project aims to develop an effective methodology for the analysis of deformation, through a Non-intrusive techniques based in laser scans, which allow both rigorous geometric study with minimal intrusion, as cost reduction to achieve economically sustainable process. Will be applied the assessment structure proposed to the case of Villagarcía de Campos Palace, a major exponent of Civil Historical Heritage in Castilla y León region, from which we will obtain an evaluation and interpretation of data for future intervention process.

1 INTRODUCTION

Cultural Historical Heritage (CH), including Civil Architectural Heritage, today performs an important role, not only in transmission of social values, but also with important economic contributions. Entities degradation by poor monitoring and evaluation structures leads to an annual loss of many buildings of great historical and cultural value. Their conservation is a crucial and delicate task and the deformations study a key element in strategies for CH recovery and enhancement.

In the age of digital culture, we must take advantage of new technologies available to give answer to those problems that everyday life offers us, and to the issue at hand: Evaluating structural deformations, is shown Terrestrial Laser Scanner (TLS) as one of the most effective tools, giving continuity to further studies of its use in structural analysis of heritage buildings [SJo07].

2 NON-INTRUSIVE TECHNIQUES BASED IN LASER SCANS FOR HERITAGE DOCUMENTATION

TLS appearance in Heritage documentation has been relatively recent, marked by a constant evolution and determined by the great advances of technology in the fields of optics, electronics and computing. The possibility of obtaining a point cloud which describes a scenario with accuracy, in some cases, less than a millimeter unit without physical contact with the object (active noninvasive sensors), described these instruments as a fundamental tool in studies related to geometry in tangible CH. [Gar11]. Structural analysis is then shown as one of the disciplines that better results can be obtained from the requirement of TLS.

There are different categorizations of Laser Scanners Heritage applications [LFA09], for our purposes, one of the best fit is determined by the scope of these devices, in turn determined by its functioning:

i. Short-range scanner "Optical triangulation or OTs": Based on the use of two laser beams of known position, which impinge on the same point. Measuring the intersection angle can be determined the distance to the point.

ii. Midrange scanner "Continuous-Wave-Ranging or CW": Based on the emission of a continuous and moderate power laser beam, from which extracts the phase difference (vibration status or position in the wave) between the emitted and received light, to estimate the flight time and hence, the distance to the object.

iii. Long Range Scanner " Ranging-Scanner or TOFs ": Based on the light pulse emission, which is reflected diffusely by the found object and the return captured by the scanner sensor. The known speed of light and time spent in the transmit-receive pulse, allow to obtain the distance to the object.

For deformation studies in CH scenarios related with Civil Architecture, last two categories are emerging as the most chords, their selection is defined by the context characteristics, the accuracy margins and user economic possibilities.

3 ASSESSMENT METHODOLOGY

The methodology is based on previous studies, which analyzes deformations from classical cartographic techniques allowing a solid basis on a small number of discrete points from Robotic Total Stations [Per09] and those that are processed from photogrammetric techniques, based primarily on stereopairs matching methods [Dar12]. The obtaining of control points are observed in long time periods to establish conduct patterns of movements and behavior of structures [Vez09], which depend not only on rigorous data recording, but also the enough time between catches to find a significant modification enabling the estimation.

In our case, we chose a solution based on artificial planes creation and its comparison with the studied shapes (surfaces), documented from TLS, minimizing the resources and time spent, with similar results and assuming an increase in process efficiency. The methodology is articulated in the four following steps:

i. Surface documentation with a higher resolution than the minimum estimated distance to check structure movements.

ii. Planes exportation on a working interface that facilitates the cleaning, data manipulation and reference geometry generation.

iii. Creationof virtual reference planes:

- Oblique Plane [A], aligned and adjusted to the evaluated shape: To determine the surface irregularities in a local frame, defined by its own mean geometry.
  - Vertical Plano [B], taken from the aligned plane [A] and pivoted around the hinge (straight formed by the virtual plane and the surface to estimate) with the elimination of ‘Z’ axis component: To determine the surface irregularities in a global framework, defined by the wall idealization (surface if we refer to the outer and inner planes) in its original state.

iv. Assessment (estimation) of distances (normal module) between the reference planes [A] and [B] each points of the cloud, representing the evaluated surface.

4 CASE STUDY: VILLAGARCÍA DE CAMPOS PALACE

The study was implemented through the deformation assessment of the Villagarcía de Campos Palace ruins. This property, declared "Assets of Cultural Interest -BIC-," is one of the leading exponents of the Palace-Castle typology of North Spain kingdoms (High Middle Ages), which combines residential functions with defensive structures in a sober formulation [Fer06].

The beginning of the Palace construction, can be attributed to the year 1183, in the midst of wars between Castile and Leon kingdoms. It is in the custody of Gutiérrez González de Quijada, man of arms in the King service, when is conducted the major restoration, printing the military character in the building. Is worth noting in history, as the Don John of Austria mansion's childhood, sent there by his father, the Holy Roman Emperor Charles V.

Different conquests, adjudications and transformations that have had throughout history, highlighting the invasion by Napoleon's troops in 1810, have accelerated the property spoliation (Figures 1 and 2 show the further deterioration in last 150 years). Although in 1969 was performed a partial restoration, the lack of continuity in the maintenance work has led to the current ruin state.

5 ASSESSMENT PROCESS IN THE DE CAMPOS VILLAGARCÍA CASTLE, INTERPRETATION OF RESULTS

Has been performed the data capture with ToF Leica C10, device that estimates the distance to the object as detailed in section [2.2]. The adequacy of this equipment in our work is based on the accuracy provided, with an uncertainty of ± 4 mm at 1-50 m distance and ± 6 mm in 1-50 m in position, maintaining a minimum spacing resolution <1mm in the entire range.

It has generated a dense point cloud, with a resolution of 1 point every 2 mm, georeferenced with a GPS station (Trimble R8), performing the cleaning and orientation using PoliWorks v.11.0.31software (module IMAlign) from InnovMetric Co. From the module IMInspect of the own program were made virtual reference geometry (oblique [A] and vertical [B] plane as noted in section [3.3]). Figure 8 shows one of the reports generated by this application for detailed assessment of normal variations.

The comparison, determined by vectors estimation, as stated in section [3.4], expose the data for two assessments, local type, allowing the appreciation of differences at individual parts levels and their relationships and, globally, where it can evaluate the behavior of the walls against the vertical and horizontal loads, as well as reflexes of foundation failures in the element.

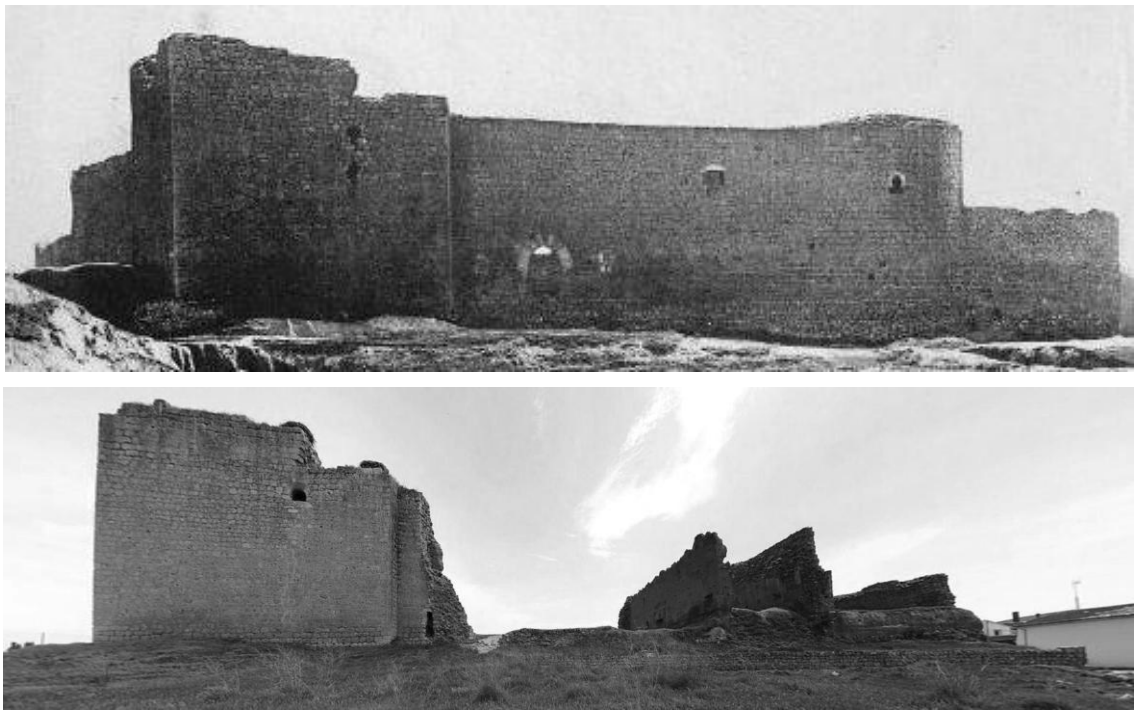

Figure 1 [upper]: Daguerreotype Stock, Northwest Castle facade, late nineteenth century, Figure 2 [bottom]: Picture taken in the same facade, March 2012.

The assessment shown in the following three sections is based solely on visual inspection and approximate geometric relationships of elements. Interpretation of structural behavior is focused on the study of the Palace Donjon, for being the best preserved region and provide the most comprehensive information. Work has been subdivided in three subprojects: Southeast facade, Northeast facade and Northwest facade, disregarding the "Southeast section" due to substantial material loss by structure collapse in recent years. They all agree on the same type of wall: Two Faces Carved Masonry, consisting of exterior rows of limestone of medium and large size in double facing form and mortar (lime, sand and water). The interior is filled with mortar, with abundant limestone and rolled pebbles. This type of construction technique and the materials used, are common in many civil-defense buildings, widespread in Christian kingdoms of peninsular area from the 11th to 13th century [Sal96].

5.1 Southeast Facade

Respect to vertical plane [B]: The comparison was performed over 6,784,000 points, with a Standard Deviation (StdDev) of 0.000621 and a Root Mean Square (RMS) of 0.0004. In this facade, shown in Figure 5, is detailed how the upper left area is offset from the bottom in order of 7 cm, explaining the presence of a tie rod, settled in the 1969 restoration, which seeks to bind the upper left section. On the right we can see the top retracted 3 cm over the bottom, in the same vertical. The cause can be attributed to structural depletion due to efforts concentration by the presence of the supporting Rampart, pushing this part of the Tower. The analysis in the inner wall has confirmed the similar behavior found in the outer, concluding that the two facing rows are well coupled.

Respect to oblique plane [A]: The comparison was performed over 3.897.000 points, with a Standard Deviation (StdDev) of 0.011397 and a Root Mean Square (RMS) of 0.0114. The assessment with the oblique plane (locally) allows to discover the presence of an inclined line quite marked in the central part of the wall, suggesting an old fissure coated with reinforcing, which has left a little outside trace on the same plane.

5.2 Northeast Facade

Respect to vertical plane [B]: The comparison was performed over 4.784.000 points, with a Standard Deviation (StdDev) of 0.010457 and a Root Mean Square (RMS) of 0.0104. Has been obtained in the map, a gradual curved outward in the vertical direction of about 19 cm, shown in Figure 6.

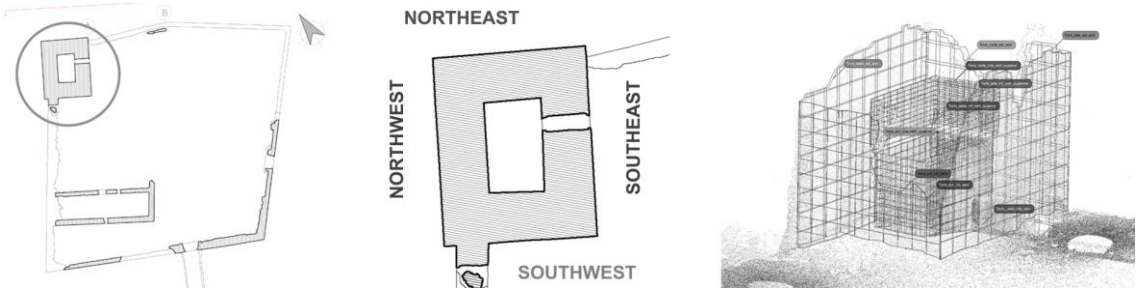

Figure 3. [left] Top view of Villagarcía de Campos Palace [center] Detailed top view of the Donjon and assessed walls [right] Plans adjusted to the internal and external Donjon faces.

Cause can be attributed to movements or resentment in foundation, by deficiency in its performance. From history we know that, based on the wealth of the proprietors, the foundation was correctly performed or simply was placed larger stones for loads transmission. Its failure implies a characteristic differential settlement of this movement respect the vertical axis.

Analyzing the inner wall can be noted the facing seems to follow the movement of the outer wall, but with a different net head, the outer face in its upper part has an inclination of approximately 19 cm, the inner barely reaches 2 cm. This means that internally, the wall does not have the same movement, due to degradation of interior fillings. Often because of an invasion of the inner content by rainwater, occurring internal material degradation by saturation, wettings or deposition of soluble salts, inner crystallization can exploit the compact structure.

Respect to oblique plane [A]: The comparison was performed over 1.783.960 points, with a Standard Deviation (StdDev) of 0.010456 and a Root Mean Square (RMS) of 0.010462. From the comparison analysis, we can observed a singular behavior zone. At the bottom there is a roughly circular shaped protrusion, probably caused by an old collapse, filled with several tons of cement and covered outside with stones, does not pose danger for the entire structure at this time.

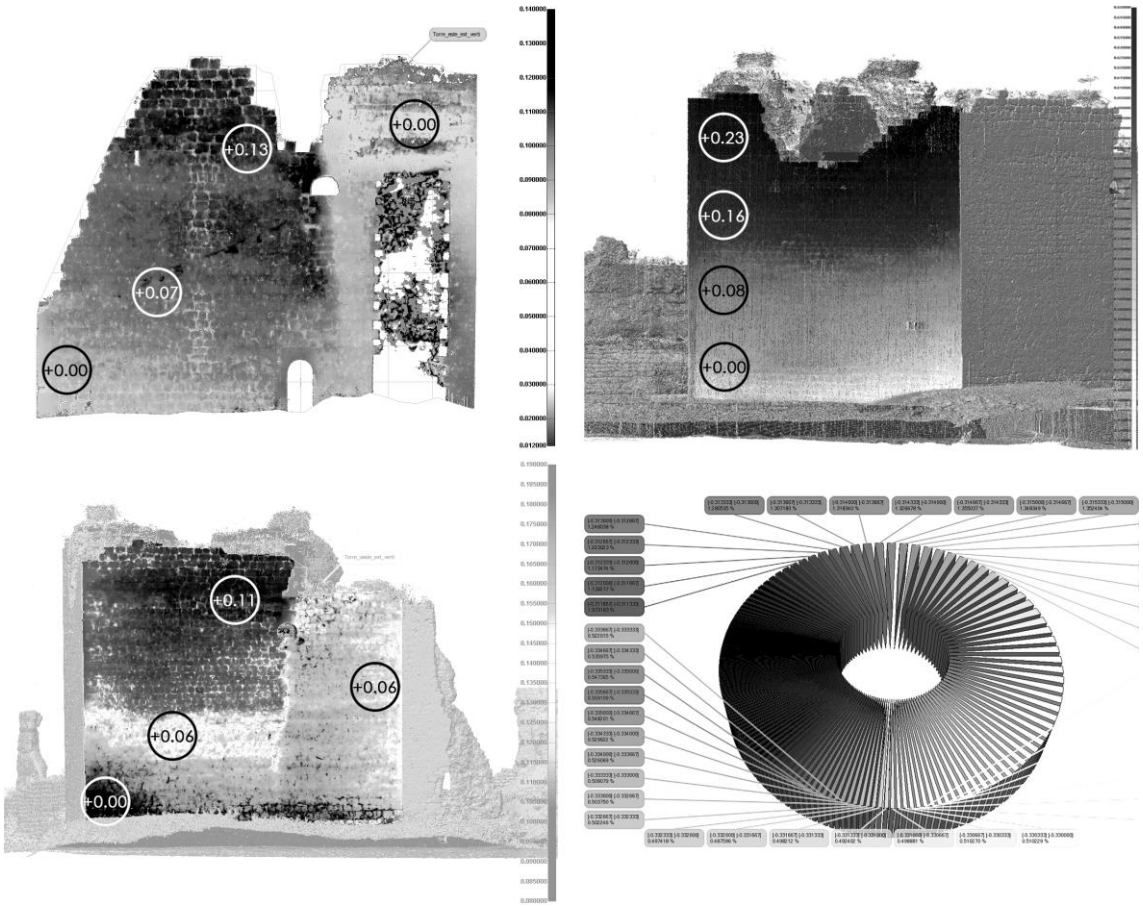

Figure 5 [upper left] Comparison between Vertical Plane and Southeast Facade / Fig. 6 [upper right] Comparison between Vertical Plane and Northeast Facade / Fig. 7 [Bottom left] Comparison between Vertical Plane and Northwest Facade / Fig. 8 [bottom right] Report generated from Polywork IMInspect for a detailed assessment of normal variations.

5.3 Northwest Facade

Respect to vertical plane [B]: The comparison was performed over 4.844.000 points, with a Standard Deviation (StdDev) of 0.00982 and a Root Mean Square (RMS) of 0.009839. Is easily visualized (Figure 7) how the left side behaves differently respect the right. We observe a vertical line dividing the two regions sharply, and is located up to the window and the internal tie rod. At horizontal level of the same left side is a vertical unevenness of 7 cm. We can guess this wall also have foundation troubles, although the tether with the tie rod in the upper region seems to compensate the movement, giving it more stability respect Northeast Facade. Inner wall behavior continues the path of the outer, so not suspected of any displacement between Masonries, indicator of the good filling performance.

Respect to oblique plane [A]: The comparison was performed over 1.787.960 points, with a Standard Deviation (StdDev) of 0.00984 and a Root Mean Square (RMS) of 0.009838. Can be noticed some irregularities in the middle and at the vertex with the rest of West facade due to degradation of the stone. Its basic cause is founded in the surface exposure to the area of greatest winds influence, intensifying erosion by exposure to water and temperatura and identifying problems of material detachments.

6 CONCLUSIONS

The methodology proposes through Non-intrusive based techniques (TLS), is possible an assessment process of structural deformations in Civil Architectural Heritage with the lowest risk in its degradation by manipulation and with greater efficiency in terms of economic and time cost. These advantages allow us to consider this tool against current solutions based on classical and photogrammetric surveying techniques and raise the possibility of joining in present studies in heritage conservation related to structural analysis.

The implementation of the assessment in the particular case of Villagarcía de Campos Palace showed an appraisal of possible diseases and their causes, with an investment of time and costs lower than those hitherto achieved. The refinement of this interpretation will be better, while there is a deep understanding about characteristics and scale of the nature of deformations, as well as the possibility of an adjusted verification of potential damages.

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