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DETECTION OF STRUCTURAL PATHOLOGIES IN BUILDINGS USING ARCHITECTURAL PHOTOGRAMMETRY

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Environmental pollution and natural degradation of materials cause deterioration in buildings, initiating pathological processes that require conservation actions. Architectural Photogrammetry will be discussed as a tool to identify different pathologies on buildings and to accurately measure deflections. A photographic study was conducted of the most common deflections on reinforced concrete structures, with samples of different ages and locations exposed to various environments within Holguin Province in Cuba to detect deterioration characteristics, causes and possible treatments. A comparative analysis of other common methods and instruments currently used to measure structural pathologies highlights the efficiency of architectural photogrammetry. Photogrammetry is suitable to study the most common pathologies, their causes, and potential solutions. These include: cracks, fissures, deflection in beams, footing settlement, slenderness in columns, and more. In addition to the scope and efficiency of photogrammetry, this technology also facilitates studying inaccessible points on large elements. The instantaneous recording of accurate data about physical objects gives photogrammetry advantages over conventional structural analysis methods.

Keywords: Crack measurement, Beam deflection, Environmental pollution, Deterioration, Structural analysis.

1 INTRODUCTION

1.1 Initial Situation

The conservation of historic buildings requires the detection of pathologies affecting the structure. Several methods are available, although they can be laborious or subject to inaccuracies. Due to unfavorable climate conditions in Cuba for historic buildings combined with incorrect maintenance management, large parts of existing historic buildings are in a notoriously deteriorated condition. Because of the large numbers of employees and expensive work needed for existing pathology detection methods, these methods lack feasibility for conservation of historic buildings in Cuba.

1.2 Problem Definition

There are high numbers of buildings with structural degradation in the island. Such a situation demands a broad and conscientious maintenance program in place; it must consider the economic planning of the conservation work, the estimation of materials, equipment and labor, the use of innovative tools, and support for the construction plans in the face of resource deficits. Traditional methods of measuring pathologies involve being in direct contact with the object and making repetitive measurements from specific reference points, a cumbersome and laborious task. In this research we propose a novel and effective tool to measure structural defects: deflections, detachments, abruption, corrosion in metal elements, buckling, bending, collapsing, twisting, displacements and settlements in foundations, columns and beams, loss of cross section in loaded or unloaded elements, unevenness between parts or sections, floors, foundations slabs, etc. It allows to take pictures in the field and then generate a follow-up file for the cabinet work for database generation for future work and planning.

2 STATE OF THE ART

Diagnosing a building pathology requires accurate measurements to determine its causes. However, obtaining measurements of dimensions with pinpoint accuracy is difficult when these points are out of reach. Architectural photogrammetry is an excellent tool to measure dimensions of pathologies with millimeter accuracy caused by normal use, design errors, building defects, accidents, and even hidden or apparent defects that may induce future anomalies.

This technology began to take shape in mid-90s in USA, Germany, United Kingdom, and others. Around the year 2000, Latin American countries and the Caribbean began to involve themselves in these initiatives, mostly at a theoretical level.

The University of Holguín, began approaching this technology in 2006 by initiating joint investigations with the “Photogrammetry, Remote Sensing and Geoprocessing Laboratory” of the Federal University of Santa Catarina in Florianopolis (LabFSG), Brazil. In 2009 the authors coordinated the international network under the Ibero-American Program of Science and Technology for Development (CYTED) called REFADC: "Ibero-American Network for the Application of Digital Architectural Photogrammetry and GIS for the Conservation of the Historical, Cultural and Archaeological Heritage of Cities for a Sustainable Tourism Management". It included 7 countries: Cuba, Spain, Portugal, Brazil, Guatemala, Mexico, Ecuador. The application of the AP to measure and identify deflections is a significant scientific-technological advance for the construction sector in Cuba, since the conservation of the built heritage is based on detecting pathologies that affect the structures, applying several methods that usually are laborious and less efficient. This technology allows repetitive measurements from specific reference points with greater accuracy and efficiency. The project integrates knowledge and experience in the use of the photogrammetric technique, creating a detailed documentation of Cuban Built Heritage and providing the results to the rest of Latin America.

3 STATE OF RESEARCH

Traditional methods of measuring pathologies are based on being in direct contact with the object, which makes this task very cumbersome. Since 2009, Architectural Photogrammetry began to be applied in Cuba, specifically in the city of Holguín, a novel and effective tool to measure structural defects, based on pictures taken at the site generating a graphic (plans, images, 3D models), line drawing (at scales 1:20 or 1:50), also rectified photographs can be generated, orthophotographs or digital models, with the possibility of integrating them with virtual environments, generating tracking files for cabinet work.

The dimensioning of pathologies from different origins in structures with heritage values is essential to provide immediate solution (Yero 2011). Studying the pathologies, their most common symptoms and manifestations and the damage that comes with it are important steps to solve them. Always trying to study the limitations and suitability with local materials.

The Construction Department of the University of Holguín maintains the leadership in the application of Architectural Photogrammetry (Monjo and Maldonado 2002, Ablanedo 2009) in collaboration with the University of Jaén, Spain, Universidad Laica ¨Eloy Alfaro¨ Manabí, Manta, Manabí, Ecuador, San Carlos University of Guatemala, the CINVESTAV, Mérida Unit, Mexico and the Federal University of Santa Catarina, in Brazil.

4 RESEARCH METHODOLOGY

Based on the work methodology established by the "Ibero-American Network for the Application of Digital Architectural Photogrammetry and GIS for the Conservation of the Historical, Cultural and Archaeological Heritage of Cities for Sustainable Tourism Management", of the Ibero-American Science and Technology Program for Development (CYTED) began the process of taking photographs with the following equipment: Digital Camera, 18 mm Lens, Tripod, Digital Distance Meter, Flexometer, PhotoModeler 2012 Software.

4.1 Taking the Photos

After the selection of the buildings and a predetermined order, we proceed to take the pictures that are going to be the fundamental base of the process. The camera should be placed on the tripod at specific positions and at the most convenient distance from the building, allowing the camera to focus automatically at the beginning. The camera is switched to manual mode and the focal length is set, which is previously established with the camera calibration carried out in PhotoModeler software, and which will be used in all the shots (18 mm was used in this case).

On this process is important to consider the following aspects:

- Picture must be performed in a way that the angle between the camera and the model center is 90º, describing a semi-circumference.
- Picture must be taken at daytime and where there will not be shadows projecting onto the building, neglecting this might throw errors on the digitalization process (advisable to take pictures in a cloudy day)
- The minimum number of photos must be 10 and all common points must appear in at least two pictures.
- Reference measurements must be taken to check the scale accuracy.

4.2 Model Construction

PhotoModeler 2012 is used to process the pictures and the image vectorization process begins. The pathologies detected are marked and the image is studied, locating the deflections that cannot be identified at the beginning (Justel 2013). The example shown starts marking independent points that can be joined using lines after referenced. This process it's repeated multiple times though out the project. In Figure 1 the beam deflection is clearly visible, when it was measured manually the result was 12.1 cm and using Architectural Photogrammetry it was 11.9 cm.

The process continues in every picture following the same sequence initially stablished by the user. For two pictures to be oriented, 6 common points must be referenced between both pictures. In case of having a sequence of photos, where one of them does not cover the whole element of interest there must be an overlap on the horizontal axis of 60 percent and on the vertical axis (if necessary) 30 percent.

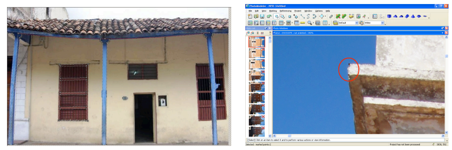

Figure 1. Demarcation of points and main lines using zoom (Justel 2013).

4.3 Pictures Orientation and Line Drawing

For the photo orientation, points are identified in the dimensions X, Y, Z that way the program has information in the vertical, horizontal and depth axes of the model and it can be located in the space. Once the pictures are oriented with a considerable number of points distributed in a homogeneous manner, the information is processed. The residual error and the proposed software suggestions are observed. A residual error of up to 5 pixels allows you to continue working in an acceptable manner. As the points in the images increase, the residual error decreases, but it must be corrected using the point quality table, which indicates the location of the point with the highest error (Justel 2013).

To start this process all interest points will be selected on the origin picture, the point to be referenced will be highlighted and, on the second picture an approximate location will be marked, Once this process it's been done the pictures will be referenced, saving time compared with manual methods.

The referenced pictures are evaluated to guarantee that all points have been marked, then the images are processed, to determine if the total error is within the permissible range, this can be represented visually in a shape of a vector that will appear at each point of the image indicating the direction in which that element must be moved to reduce its error. After the errors have been corrected the process to trace the lines starts, this can be done both in the model and directly on the photo. It is recommended to start on the picture, since starting directly on the model can be confusing while selecting points within all the elements.

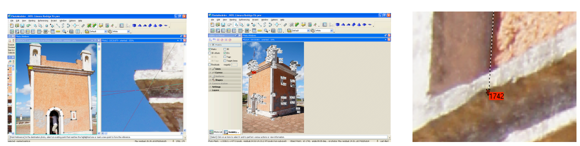

Figure 2. Left: Picture orientation. Center and Right: Selecting and decreasing Larger Residual Error Points (Justel 2013).

5 SAMPLES

A comparison between traditional method and Photogrammetry is described below.

5.1 Cracks

Cracks are the main sign of buildings deterioration; therefore, it is necessary to study them to protect the structures in time. If they are not easily visible, the picture can be treated digitally to obtain different tones, lighter or darker, to define the size of the crack, then the image is treated with the Photomodeler, to measure its length, and width.

To create the crack model, it can be traced and measured using the measurement tool without the need of reference it with other photos. It can also be determined if the crack is active or not, taking several pictures throughout time and comparing them to detect any dimensional change (Justel 2013).

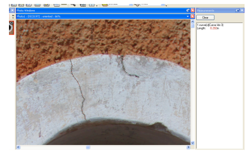

Figure 3. Crack-image degradation (Yero 2011). Figure 4. Length of the selected crack (Justel 2013)

5.1.2 *Comparison of crack measurement with crack measuring gauge equipment*

In the Material Testing Lab at the University of Holguin, a Crack Measuring Gauge equipment is traditionally used. It is placed perpendicular to the study wall and its amplitude is measured directly with the equipment, its mechanism works according to the development of the crack, the reading is recorded on a display with an accuracy of hundredths of millimeters. It is required to drill on the wall and fix the instrument during the time of the measurement, with the disadvantage that workers must be located very close to the crack to be evaluated (Zucatelli 2009).

Figure 5. Using a Crack Measuring Gauge (Avşar *et al.* 2014).

Table 1. Measurement results comparison between AP and traditional methods.

Dimensions	Measured with AP*	With Measuring Gauge	With measuring Tape
Crack Length	0.202 mm	No	-
Crack Width	0.032 mm	0.030 mm	-
Residual Error	0.0001 mm	0.030 mm	-
Beam Deflection	11.01 cm	-	12 cm
Residual Error	0.0001 mm	-	1.0 mm

*AP: Architectural Photogrammetry (Avşar *et al.* 2014)

5.2 Beam Deflection

Beam deflection is a pathology of difficult detection by visual methods, it is considered dangerous because it can be a sign of the proximity of collapse. To measure it manually is a complicated process especially when they are of small magnitudes and in high-rise structures requiring scaffolding and several operators to handle the instruments, increasing the operation time. To measure deflection using photogrammetric methods, it is necessary to take photographs with references, like a point or object that is in a horizontal state. Figure 1 shows the beam deflection, and Table 1 reflects the comparison and margin of error with traditional methods.

5.2.1 *Beam deflection in bridges*

AP has been also applied to bridges studies in Holguin Province, using 3 bridges as a study sample with 25, 33 and 40 m of beam length. Photogrammetry was used to study dynamic vertical deflections and an accelerometer to register acceleration due to regular traffic. After a rigorous analysis and comparison, results showed that measurements obtain by photogrammetric methods where almost the same than the ones obtained by the accelerometer. Proving that the new technology can be used with accuracy providing also advantages such as: It is easier to obtain the measurements and it is cost effective, allowing better access to large structures; also offers great accuracy (compared with lab tests) with a margin of error on deflections of 0.1 mm and measuring frequency of 0.1 Hz.

Although in the pass lasers and software have been used to measure deflections (Avşar *et al.* 2014, Inzunza 2014, Rodríguez *et al.* 2017). Comparing the use of modern equipment like total stations and 3D laser scanners, lab tests and photogrammetry, it can be concluded despite the several methods to obtain this results, each one of them with its pros and cons, the use of conventional cameras offers great precision, it is cost effective and easier to use on large structures where access is limited.

6 DISCUSSIONS

Using Architectural Photogrammetry, many common pathologies can be studied and detected, their causes and possible solutions. It allows to reach inaccessible points on large elements. Its ability to obtain secure information on physical objects through images, constitutes its main advantage since it allows orienting pictures, creating points, lines and planes and extracting textures. The result can be exported to other software's such as AutoCAD, ImageModel, Rhino, Google SketchUp, etc. Which would increase the efficiency of the process of detection and measurement of structural pathologies.

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