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IMPROVING OF INDIRECT MEASUREMENT SYSTEMS TO REPAIR STONE ELEMENTS IN SINGULAR CONSTRUCTIONS

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Abstract

In the process of repair and reconstruction stone structures, it is as important to know the causes of its deterioration as the shape and geometry of its elements. This is due to the rigid nature of the stone material because only it is possible to transmit efforts by compression. The author of this paper is working with new measurement systems based on laser technology to do collecting data in singular buildings made with stone. The great accuracy of these systems is ideal for these cases. However, due to its static nature, very often it is not possible to obtain all of the data, so it must complete the information by other means. To resolve this issue, this system has been combined with others as photogrammetry, getting an interesting solution not only from the structural point of view, but also by its value as graphic document.

Key words: *stone structure, data collection, laser technology*

1. INTRODUCTION

The stone as support is present in the construction of the most of cultural goods that form our architectural heritage, for whose preservation is essential to carry out interventions whose application depends on how the building is and the knowledge about it we may have.

In this sense it is very important to get a good prior documentation to the analysis and subsequent intervention, both historical as planimetric. In fact, it is not possible to carry out the studies required without it, such as the constructive analyses, typological and formal or even structural studies, and from which to obtain a right proposal for intervention on the constructed element, whether for repair, replacement or reconstruction it.

So we can say that the final result depends largely on the accuracy of the documentation that describes building geometry, construction and pathology before the architectural intervention. Then, any work of this type must be preceded by comprehensive information from which it is possible to develop the right techniques in each case.

In this type of interventions, the most suitable methods for collecting data in situ, which are necessary to generate the previous documentation, are indirect measurement systems, due, in large part, to the difficulty of direct access to a lot of the intervening elements that usually offer this kind of construction.

In addition, to being non-intrusive methods work is performed without altering the object of study, feature that in buildings of great historical interest, such as that in this work are presented, is not only a value-added but necessary requirement.

Currently, using laser technology and photogrammetry, it is possible to make an architectural survey with great precision and efficiency. Thanks to the million points obtained, it is possible to generate a three-dimensional virtual model of the object we are studing.

This article presents a methodology that combines the two technologies referred to above, and which has been developed by the research group of the architectural heritage of the Department of industrial systems engineering and design of the University Jaume I of Castellón as an alternative to the architectural survey with topographic traditional systems for the realization of the corresponding graphical documentation that serve for the further analysis and proposals for intervention in different religious buildings built in stone belonging to the Mediterranean Gothic.

2. METHODOLOGY

Thanks to the continuous work done by the research group of the architectural heritage of the University Jaume I of Castellón, in which has been able to test different systems to carry out an architectural survey, has developed a work system, supported in the use of new technologies, which allows to optimize the time and resources invested in this run-up to the stereotomy studies and proposed intervention in stone structures.

While both the system for laser scanner and Photogrammetry allow to perform a whole architectural survey without the need of other means, the combined use of both systems allows to get maximum use of each of them, besides improving the accuracy of the final result.

In this way, thanks to the system with laser scanner we obtain information from an enormous amount of points in a relatively short time. In addition to the location of these millions of points, this system gives us information on the brightness and color of each of them.

With this process we get so many point clouds as number of sweeps have been executed with the scanner, from which you can generate a realistic virtual representation of the object to analyze. The definition of this model depends on the density of the point clouds and gaps or shadows that occur when taking data.

On the other hand, also by photogrammetry system, it is possible to determine the geometric and radiometric properties of an object, however, in this case the data are obtained from only photographic images, which eliminates the restrictions of positioning posed to move heavy equipment of the laser scanner, because data is obtained with a simple camera, which also means a saving in economic investment to make with respect to the first system.

However, the work of the data processing is more elaborate, that unlike the scanner laser data are not obtained directly but we need to get them through specific software, so it has to invest a greater number of work hours to get accuracies similar to which offers us the system by laser scanner.

In summary, the elaborated methodology is developed according to the following phases or stages of work:

- planning
- data collecting
- data processing

While the work is done by combining the two systems of measurement exposed, due to the differences between the equipment that make up both system, each one of the stages of work are handled separately, contrasting and combining the results after the data processing to produce the relevant documentation.

3. PLANNING

3.1 Indirect measurement system by laser scanning

Although the limitation of the density of the point clouds that records the laser scanner is determined by the used equipment, in such a way that it is possible to determine first the distance between the points to be measured, gaps or shadows in these point clouds depends on two external factors:

- the possibility of parking the equipment in the right places to complete measure of the element, and,

- the existence of objects which hide the surface of the element we are analysing and that is not always possible to delete before scanning.

It is therefore essential to determine first the work to be carried out. So we need to know clearly the object of study, as well as which are the claims of the study, in such a way that both number and position of scans to perform and the resolution which they will made, serve effectively to the resolution of the problem.

It is not only defining the study area but take into account other factors such as the level of definition that we will need, accessibility and availability to place obstacles in the planned screening directions...

Furthermore, in the case of having to scan an area of large dimensions, should be foresee where bullseyes or control points must be put so that later it is possible to link different obtained point clouds with the scanned.

All this work is possible at the office, without having to scroll to the place where the construction causes for study is until the time of the architectural survey. However, it may be only if there is accessible documentation of the construction object of study. Otherwise, it would be necessary to make a first visit to obtain this information.

3.2 Indirect measurement system by Photogrammetry

As in the above system, previous planning to the field work ensures the correct determination of the position and number of photographs to perform. For this system, the determination of the day and time are of special importance because, unlike the Laser scanner, light is a key factor for the camera.

The use of targets or control points makes easier the subsequent work of processing the images, although texture of the used stone in this kind of construction is enough to identify homologous points.

It is also to take into account that the results depends on the link between the right images, so it is expected that each zone to represent can be photographed at least from three different positions and taking them with a considerable overlap between an image and its adjoining.

Both systems need to calibrate the cameras before taking photos. This process is carried out by the same software in the case of Photogrammetry programs, but in the case of the scanner laser has been used Image Master Calib of Topcon.

4. DATA COLLECTING

Although actual dimensions are insured with the scanning system laser is suitable taking some relevant measures of elements accessible with other direct measurement systems, for example the measuring tape and Zeiss, for possible subsequent checks.

4.1 Indirect measurement system by laser scanning

Measuring instrument used as indirect system is a Terrestrial Laser Scanning (TLS), based on pulses, with invisible laser of class one with long range, mark Topcon GLS 1500 type and accuracy of 4 mm in a range of scanning up to 150 m and 6 ' angle (2.0 mgon), linked with a 2.0 Mega pixels camera integrated and aligned coaxially. (Table 1)

Due to the limitations of the equipment which has limited their viewing angle in one of its axes, and by the geometry of study construction, it is necessary the parking of the scaner at different points. It is therefore necessary to make several sweeps with the scanner laser to obtain the necessary information from the surfaces of the elements to analyze. At the same time, the passage of each of these sweep mesh is previously defined depending on the distance and density of points that are interested in obtaining in each sweep (Table 2).

The result is a set of point clouds composed each of hundreds of thousands of individual measurements according to a cartesian coordinate system (x, y, z) and a different density of records on the basis of previously determined resolution.

As a particular rule, the resolution used for the scans of general views is less than the case of the element details because as mentioned above this setting is performed depending on the level of definition that we want to get in each case. In the studied cases, general sweeps have been used as frame of reference of the particular element of study, to place it in its context, that is in the interior of the building and therefore without the need of a great detail but with the objective of maximizing the registered surface with the minimum number of required parking, and making the reading of the corresponding control points or targets to do possible linking of the resulting point clouds.

Otherwise occurs with the point clouds of detail, in which it is more important the definition of detail than the extension scanned, in a way that the small distance between points (less than 1 cm) allows to represent unambiguous geometries of the smaller elements.

Laser Scanner	Topcon GLS 1500
Type	Pulsed
Color	Invisible (eye-safe laser)
Laser Class	Class 1
Scan Rate	30.000 points/second
Field of view (Per scan)	V- 70º (maximum)
	H- 360º (maximum)
Scan Density (Resolution)	Spot Size- 6 mm at 40 m Maximun Sample Density- 1mm at 100 m
Color Digital Imaging	2.0 megapixels

Table 1: Summary of the used laser scanning system specifications

Scanning Specifications	Scan Density	Maximun Range	Time
General views	H – 20 mm V – 20 mm	20 m	20-25 min
Detail views	H – 5 mm V – 5 mm	10 m	15-20 min

Table 2: Passage meshes characteristics of the measurements.

In this way is achieved optimizing the time of scanning process, since the time of scanning process is determined by both the resolution and the registered surface. Hence the time invested in each one of the sweeps will be similar.

In addition, thanks to the high resolution camera which the scanner includes, the point clouds will be able to appreciate altogether as a virtual representation of the scanned item, after link each registered point with the colour of the corresponding pixel in the reference picture.

4.2 Indirect measurement system by Photogrammetry

Data collecting are made using two cameras, in a way that results can be contrasted. One of them is a 10.2 Mega pixel digital camera Nikon D-80, with an objective from 18 to 135mm and focal aperture of f/3.5-5.6. The other one is a digital camera Olympus Stylus-5010. In both cases the images serve both support for a direct reading of different building elements and their application in processes of Photogrammetry (Table 3).

Therefore in this system data collecting is determined by the position and number of pictures, as well as the resolution of each of them. Then, the correct position of the camera and the appropriate number of photographs allows us to ensure the necessary continuity between the different photographs that run through each studied element image.

Cámara	Nikon D-80	Olympus Stylus-5010
Image Sensor	RGB CCD 23.6X15.8 mm 10.75 million total pixels	CCR 6.13x4.60 mm. 14.50 million total pixels
Sensitivity	100 to 1600 (ISO equivalent)	64 to 1600 (ISO equivalent)
Exposure metering	3D Color Matrix Metering II Center-Weighted Spot Metering	3D Color Matrix Metering II Center-Weighted Spot Metering

Table 3: Used cameras characteristics. www.nikon.com. www. olympus-global.com

To achieve this, between photo and photo camera position must be moving between 0.15 and 0.25 the distance that they keep with the object. For example, placing the camera to 3.5 m from the being photographed object, between a camera position and the next should be between 0.5 and 0.9 m, this is

about a step. In this way, the shortest is the distance from the object, the greatest number of pictures is made and therefore the geometry of the element is recorded in greater detail.

In addition, the resolution of each photograph depends on the used values in each different photographic parameter, such as the opening of the diaphragm, degree of ISO sensitivity and shutter speed fundamentally (Table 4).

Cámara	Nikon D-80	Olympus Stylus-5010
Resolution	300x300 ppp	72x72 ppp
Sensitivity	ISO100	ISO 64
Exposure time	10 seconds	2 seconds

Table 4: Picture characteristics

His determination is based on the kind of used camera. For the digital camara Nikon D-80, it must be put the ISO-100 and the F/11 or F/16 aperture from manual mode. After the camera is positioned in front of the object, we focus using the automatic mode and again passed the camera to manual mode. In this way we get the focal length does not change. Finally, we chose the rate of fire so that photography is a bit overexposed, with the aim that the sensor takes the best possible information. To achieve optimal results it is recommended using the tripod because, although it depends on the light, the shooting speed will be slow and freehand camera movement subtract sharpness to the image. In this sense, a trigger is used by cable and of course the shot is delayed to avoid movement of the camera that is very harmful in photogrammetry. It is also recommended lowered mirror previously, because reflex cameras always mirror is lowered automatically when the photograph is made, but there is usually an option in which you can program to be lower in advance and not a few moments before the shot. All of this aims to avoid the trepidation of the camera and to obtain sharper pictures that we can.

For the compact camera Olympus Stylus-5010, the procedure is similar but with the fixed target.

It has rejected the use of other types of lower-end cameras because we would not have the possibility of adapting all the above parameters, so we should use the camera on auto, which makes dependent on the result that we are able to photograph at the same distance and the same conditions of light, so that the camera adopts the same provision. But of course, it would be suitable to use tripod and naturally delaying the shot to avoid camera movement that is very harmful in photogrammetry.

5. DATA PROCESSING

5.1 Indirect measurement system by laser scanning

Depending on the results which are required, the processing of point clouds can be more or less elaborate. In this way, it is possible either to get results directly from the point clouds and generate a three-dimensional model from them. The longer the processing is the bigger the deviating is from the results, as represented surfaces are obtained by interpolation from data, introducing new points that do not have to match the reality.

The level of processing depends on utility that results bring. Thus, for the subsequent analysis about the material and superficial pathologies data are processed to create textured surfaces which are generated as a triangulated irregular network (TIN). However, therefore geometric and structural analysis of the construction it is recommended to use the point clouds directly, as it prevents so possible deviations in the representation of drawings and generating sections of the various elements that make up the building.

This process is carried out by means of the specific point clouds processing software. A first data is treated with own programs of the laser scanner, Topcon ScanMaster and ImageMaster, which scanner data are imported and are transformed into the corresponding point clouds which can be linked thanks to the checkpoints. In this way, it is possible to view, measure, and edit a first model of three-dimensional data directly from the point clouds.



Fig 1. Church of San Mateo. Orthophoto of the flat interior obtained directly from the point clouds captured with the laser scanner.

If it is also applied to each point its texture, linking the points with their corresponding pixels of the photographic information, we get a first virtual model which we could extract orthophotos (Fig. 1) that help and enrich the layout of the traditional planimetry: floors, elevations and sections.

Next phase is to export these first results in different formats such as DXF, JPEG, VRML, OBJ, consistent with several software which allow to make representation and graphic analysis or for generating and treating mesh surfaces.

The geometrical analysis is made using CAD programs, most suitable for this kind of work but have the disadvantage of not managing well the point clouds due to the excessive amount of contained data in each file. For this reason, it is necessary to reduce the size of the point cloud, dividing it in different parts (Fig. 2) or incorporating any specific plug-in as the case of Leica Cloudworx or Kubit Pointcloud, both for Autocad.

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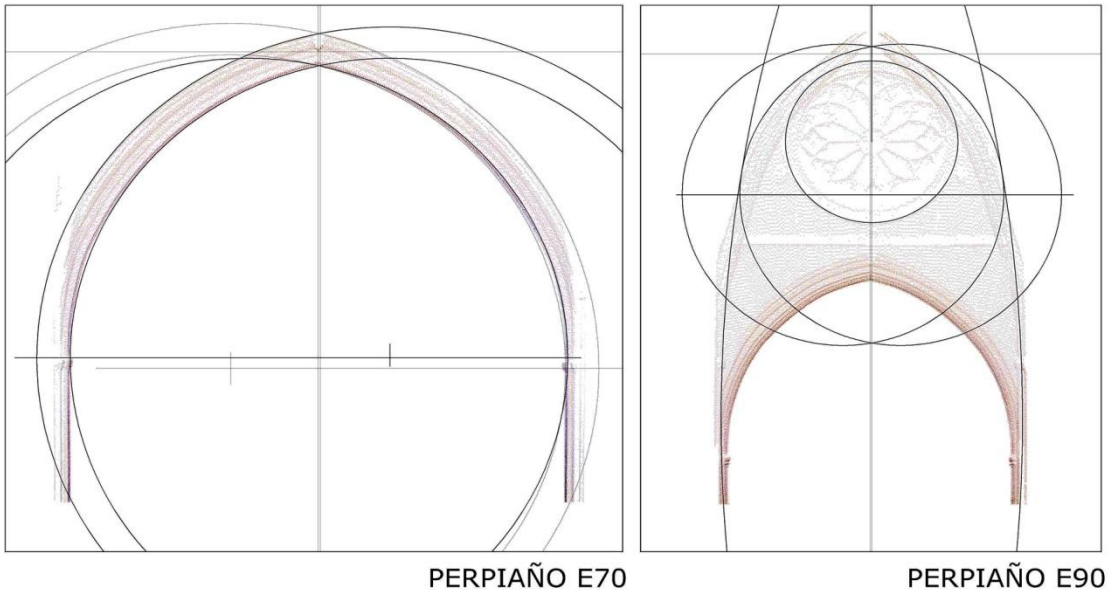


Fig 2 Church of Santa Maria in Morella. Geometric analysis of the structural elements with the Autocad program directly from the clouds of points exported in dwg format.



Fig 3. Chapel of the Church of Santa María de Morella. Textured surface after data processing using Photomodeler software.

It is outside the scope of the present investigation to obtain a whole three-dimensional model of the studied building, although it should be noted that to carry out it is necessary linking the different point clouds, thanks to the use of targets or control points, furthermore to fill inevitable gaps or shadows which are produced by this system of laser-scanning, using the information from photographs.

5.2 Indirect measurement system by Photogrammetry

How it has been mentioned above, unlike the system with laser scanner, in photogrammetry cannot be results without processing registered data, photographs, using specific software, which means not having the point clouds directly, but it is necessary to generate textured 3D surfaces at the first moment.

At the same time, thanks to this characteristic, the more work the data the more accuracy we obtain, just to contrast with the laser scanner. This is because in photogrammetry, the amount of points are determined when processing the data, not when they are captured, so it is possible to generate different resolution three-dimensional models of the object to analyze, without making new records.

Then, as for the subsequent analysis on the material and pathologies surface as for structural and therefore geometrical construction analysis data are processed to create the corresponding textured surfaces (Fig. 3), although with a higher density of points for the geometric study, looking as above to minimize the possible deviations in the representation of the layouts, and generating sections of the several elements which make up the building.

Different specific programmes of Photogrammetry are used for the treatment of images, among them Photomodeler and Asrix, which provides three-dimensional additional models of the unique elements of the construction system of the building, as well as orthophotos (Fig. 4) that help and enrich the layout of the traditional planimetry: floors, elevations and sections.



Fig 4. Church of San Mateo. Orthophoto of the Omni plant obtained from the textured surface after processing of data with the 123Dcatch of Autodesk software.

As in the case of the laser scanner, it is also possible to export these results in different formats such as DXF, JPEG, VRML, OBJ, compatible with various programs to make its representation and graphic analysis or for generating and treating of mesh surfaces.

Nowadays, thanks to the breakthrough that Photogrammetry has suffered in recent years, it can be found online software for processing images that, as usual, offer basic services for free. This is a great savings of time and costs, and even though they are not recommended for a final result, the precision obtained with them is very useful for the first three dimensional readings of the object to analyze.

6. CONCLUSIONS

The application of this methodology shows the compatibility of two measurement systems which are generally used independently. It can be seen from the earliest stages of the architectural survey because their combined use implies a significant reduction of the time and required operators because it is possible to overlap tasks during data capture using the time in which running sweeps with the scanner laser to make photographs that later we will process using Photogrammetry.

At the same time, the previous planning to the completion of the field work, acquires here a great importance, not only to ensure the correct and complete information, as it is the case with each of the two systems separately, but to avoid unnecessary duplication and establishing the programme of work suitable for every occasion.

There are also improvements in generating the graphic documentation because as textured surface are got by photogrammetry, we don't need to make this work with the data from the laser scanner, whose point clouds are directly used for the development of geometric studies. It assures maximum accuracy of the regulator layouts of constructive elements.

On the other hand, textured surfaces generated by Photogrammetry are the best instrument for the study of pathologies because the data are reported precisely thanks the lightness values of the photographed surface.

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