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Masonry structures assesment and photogrammetry. Case study: San Millán de Segovia

Evaluación de estructuras de fábrica y levantamiento fotogramétrico. Caso de estudio: San Millán de Segovia

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- A complex photogrammetry technique can be used as a geometric base to analyze masonry structures.
- The rapid processing of the geometric data is feasible when we need to adapt them to the requirements of the different stability analysis methods.
- The use of photogrammetry allows to determine the exact geometry and position of the historical masonry walls when they are seen outdoors.
- The combination of detection systems with the analysis methods can be of great interest in cases in which we need a quick survey.

The advanced technology of the new photogrammetric systems, whose progressive improvements could be due to both better resolution of the new cameras and the recent development of sophisticated interpolation algorithms, permits nowadays register not only the general aspect of the building architecture plan and elevations but also, learning in detail the geometry of the parts that integrate the building, and more significantly, the main elements of its structure. In fact, it has a great interest in many areas, and specially in masonry structures, where stability analysis require detailed information about the structural joints of the materials that set the element as well as the specific geometry of the junction that appears between the contact of one block with another. In this work, we demonstrate that a complex photogrammetry technique can be used as a geometric base to analyze masonry structures. The San Millan de Segovia's church is used as an example of structure for the study. This study addresses the different parts of the process, from the photogrammetric lifting to the simplification processes used for implementing this procedure automatically to any type of structure, pointing out the operational simplicity that this technique allows.

Photogrammetry; Masonry walls; Arches; Ortophoto; Photoelasticity

- El levantamiento fotogramétrico complejo es empleado como base geométrica para el análisis de una estructura de fábrica.
- El rápido procesado de los datos geométricos para adaptarlos a los requisitos de los diferentes métodos de análisis de estabilidad es factible.
- El uso de fotogrametría permite determinar la geometría exacta de los aparejos que componen una fábrica histórica cuando estos son vistos al exterior.
- La combinación de estos sistemas de detección con los métodos de análisis puede ser de gran interés en casos en los que se precise de un peritaje rápido.

La precisión de los nuevos sistemas de registro fotogramétrico, cuya progresiva mejora puede atribuirse tanto a la elevada resolución de las cámaras modernas como al reciente desarrollo de sofisticados algoritmos de interpolación, permite en la actualidad registrar no solamente las trazas generales de la planta y los alzados de un edificio sino, además, conocer en detalle la geometría de las piezas que lo componen, y muy señaladamente de los elementos que forman su estructura. Este hecho es de gran interés en muchos campos, y especialmente en el ámbito de las estructuras de fábrica, ya que los análisis de estabilidad de éstas precisan (al menos cuando se pretende incorporar al estudio el comportamiento local) de información detallada sobre la articulación de los materiales que las componen: trabas, aparejos o geometrías específicas de los lechos en los que unas piezas entran en contacto con otras. El presente trabajo desarrolla un caso concreto, el de la iglesia de San Millán de Segovia, un edificio en el que el levantamiento fotogramétrico complejo se ha empleado como base geométrica para el análisis de la estructura de fábrica. En este estudio se desarrollan las distintas fases del proceso, desde el levantamiento hasta los procesos de simplificación geométrica necesarios para poder implementar cualquier tipo de análisis estructural de forma automática, poniendo el énfasis en las facilidades operativas que posibilita esta técnica.

Fotogrametría; Estructuras de fábrica; Arcos; Ortofoto; Fotoelasticidad.

1. INTRODUCTION

The behavior of masonry structures, especially those belonging to historic buildings, is elusive. The security of these structures can be guaranteed in terms of global stability (commonly used methods to calculate it are, for instance, traditional drawing methods and linear programming [1][2]). However, local behavior problems, which can lead to severe pathologies, are difficult to predict. In this type of structures, the resistance of the material is not as important as the internal geometric organization of the material: masonry walls are heterogeneous, anisotropic and discontinuous, and this greatly hinders its analysis.

Knowing with precision the distributions of the bricks, the geometry of its joints or even its thickness, allows to have a more precise evaluation of the local behavior. This is, in fact really difficult in historical structures, in which the data acquisition must be as harmless as possible [3]. Current topographic techniques can help to solve this problem.

2. Practical example: San Millán de Segovia

To verify the applicability of these survey techniques in the analysis of masonry structures, a detailed study of an historical building was carried out.

San Millán de Segovia church (Fig. 1) was selected for the study. This magnificent building is elevated in the old 'Arrabal Mayor' of the city of Segovia, built out of the walls of the medieval city and near the river Clamores [4]. The constructive origins of this church have not been dated with accuracy but could be placed at the beginning of the 12th Century.

The church has undergone various changes from its earlier construction to the present time [5][6]. Clearly built in Romanesque style, San Millán has three naves, with the main nave bigger than the side aisles. A presbitery and a semicircular apse are located at the end of each nave. Also, a singular vault of crossed arches is raised on its transept [7]. Finally, the church has two covered access atriums on its north and south façades, as well as a tower and a sacristy [8].

San Millán is one of the biggest churches in Segovia, and thus we limited the photogrammetric study to the structure of the south façade and its entrance atrium. This area was selected due to its good access and also for not being surrounded by buildings or urban elements that hinder its complete vision and obstruct the photographs.

We can realize that the south atrium we can see today was restored during the 50s [9][10], when its arches were freed of the walls that blinded them and the several constructions were attached to the church walls were demolished. This work contributed to recover the Romanesque aspect of the church.

2.1. Data collection

For preparing the photogrammetric study itself, general and particular photographs of the element and a software to process them are needed. In this case, we used a reflex camera (Nikon D3000) with an extendable tripod to better stabilize the image. Agisoft PhotoScan Professional v.1.2.6. [11] was the software used for photographic processing and to perform the photogrammetric investigation.

To obtain an optimal study, the analyzed photographs had to be taken in hours and climatology that favors the lowest appearance of shadows in the studied area. In addition, we took all the photographs with the same focal distance, mode and zoom for better processing in the software.

It is always necessary to take several photographs, including general areas, details and problematic areas as columns, windows and roofs.

It is also important to surround the maximum area of the building and keep the same distance all the time, trying to have an overlap of 2/3 of the image taken with respect the previous one. Taking all this into account, our study will start from 81 pictures.

In addition, it is necessary to carry out a complementary analysis of the area studied that supports the previous mechanical process.

For this purpose, sketches and measures of the façade were made, as well as a historical study of the church and its surrounding for a better understanding of the building and its characteristics.

Figure 1. South façade and atrium of San Millán de Segovia.

2.2. Photogrammetric software

The processing using the Agisoft PhotoScan Professional software is divided into 8 stages, starting with the insertion of the photographs (at maximum quality) and finishing with the export of the orthomosaic generated.

During the process we rely on the sketches and measurements taken to include points referenced in the mesh that allow PhotoScan to create the image at scale and real size. The final elaboration of the orthomosaic of the south façade took about 14 hours of photogrammetric processing.

Figure 2. Ortophoto obtained with Agisoft PhotoScan Professional software and exported to JPEG.

The orthomosaic obtained as a photogrammetric result (that can be exported in different formats, including JPEG or TIFF) is a high-resolution georeferenced orthophoto with density and detail at a scale of 1: 1.

The cloud and mesh obtained in the program allow us to visualize the studied element in three dimensions and move through its interface to analyze details or specific areas (Fig. 3).

By means of this technique, the rest of the façades and even the building interiors can be raised, which would allow to have a 3D model of the building

Figure 3. Software interface image obtained by Agisoft PhotoScan Proffesional. South façade.

2.3. Plans elaboration

Once the orthophoto is obtained, the detailed plan of the masonry under study can be elaborated by means of any graphic treatment software. The case that concerns us was performed with AutoCAD v.2014.

Due to the traditional process used here, it was necessary to add the orthophoto as a base in AutoCAD 2014 [12], scaling it and using it as a basis for the new drawing (Fig. 4).

Some programs, as Rhinoceros or Revit, could export the mesh generated by PhotoScan in 3D format as a cloud of points that are used as support, since the cloud already has scale and correct measurements. This second version would be also ideal if we needed to draw elements in three dimensions.

This is possible with the current programs of vectorization on a photographic basis, and most importantly, the passage from photography to drawing is almost automatic. These techniques therefore allow a rapid redrawing of the georeferenced high resolution orthophoto. What is more, the ortophoto exported works as a kind of template that allows to draw above all the elements needed to make up the plan including the determination of the layout of the external parts of the bonds. In this way it is possible to obtain, in a few steps, a very precise lifting of the external appearance of the bricks, knowing even the thickness of joints (only in certain types of masonry, of course) and an estimation of its distribution, although the real internal geometry remains the scope of these methods.

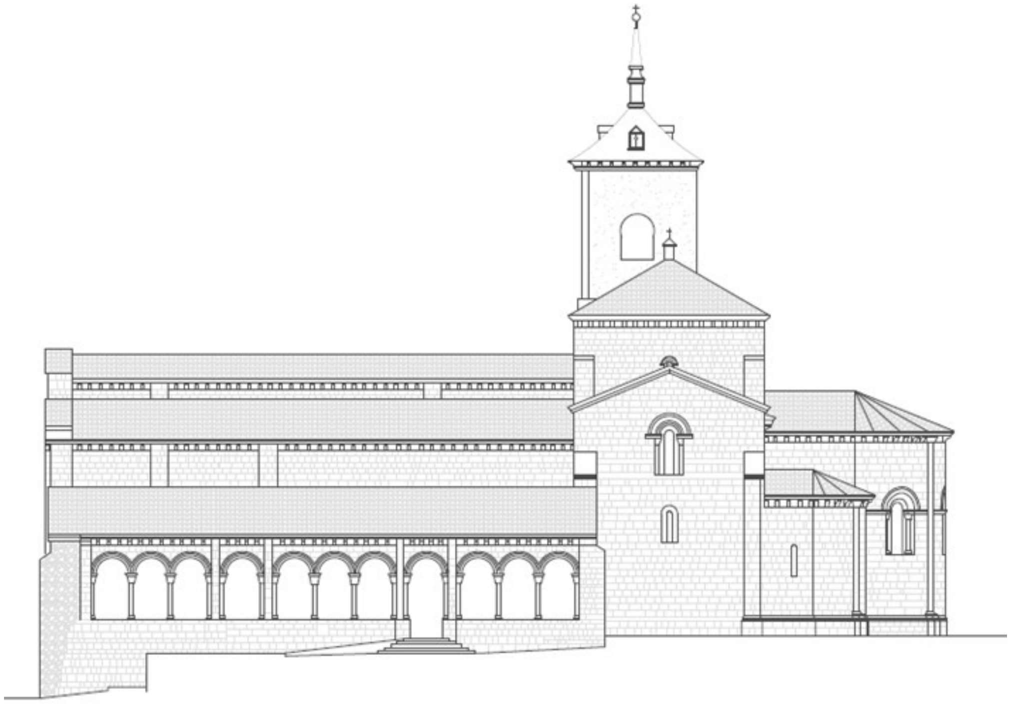


Figure 4. South elevation made with AutoCad 2016 based on PhotoScan mesh exported

2.4. Working with the models obtained. Adjusted simplifications

Once the geometry of the masonry has been precisely determined (by the quasi-automatic method described above or by traditional procedures) it will be possible to analyze the safety of the structure.

However, at this stage a small problem may arise, as a consequence of the high precision of the obtained model: that the graphic result incorporates excessive information can make the implementation of certain methods of structural analysis complicated.

In general, these methods require a model adjusted to the standards of the computer, graphic or test procedure to be applied, so that the geometry obtained through the procedures described in 2.2. and 2.3 may need a cleaning process in order to adjust to the requirements of each method.

This operation, basically a simplification of the detailed model, can also be automated with the same vectorization programs described in 2.3.

For instance, Meshlab v.2016 [13], offers various alternatives for simplification, refining, smoothing and surface remapping. It would be sufficient only to modify the precision parameters of the lines that make up the masonry, its verticality or the expected joint thickness.

However, this step is complicated, and attention must be taken: the simplified model obtained with AutoCaD must be adjusted as accurately as possible to the original, in order to ensure high accuracy of the local analysis is high. It is important to point out that local problems in masonry structures usually have their origin in stress concentrations [14].

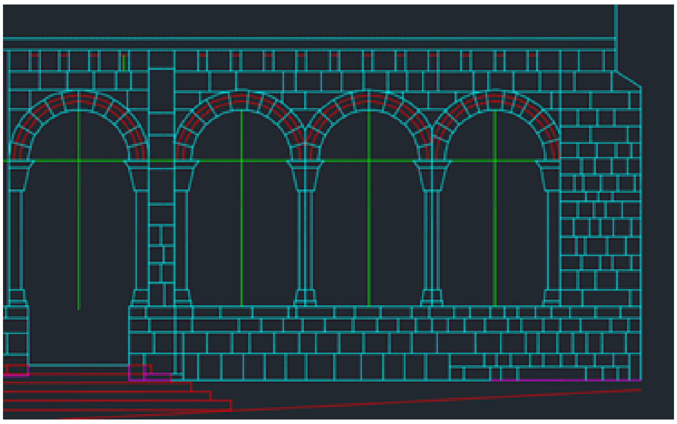
The orthophoto detects these special points but the simplifications can obviate them. In conclusion, it is important to accurately adjust the simplified model, within the limitations of the method used in the analysis, to the original case.

For the study described here, the structural analysis was carried out using different methods: photoelastic tests, analysis by drawing methods and by discrete elements [15][16][17]. In all of them it was necessary to simplify the masonry bond obtained in order to analyze, group and fuse the masonry areas into other equivalent ones, without modifying the arrangement of the horizontal and vertical joints.

Photo-elastic models of the blocks were made as a complement to a final master's project [18].

An atrium model in resin was designed and cut, adjusting the measurements of the confiter that contains them (40x30 cm).

The layout of the cut incorporated many of the irregularities of the masonry, but it was adjusted to the minimum possible piece size for the subsequent laser cutting.



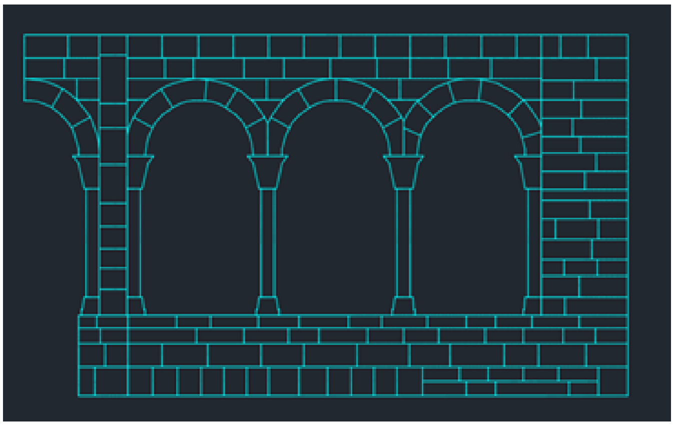
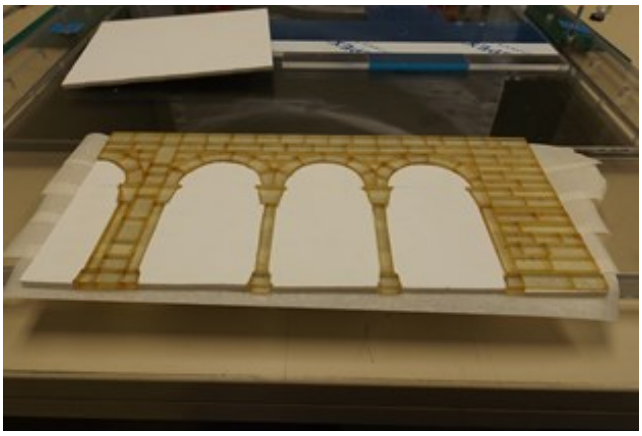


Figure 5 (a). Original atrium drawing. Figure 5 (b). Simplified atrium model done with AutoCad and used in DEM.

Figures 5(a) and 5(b) show the difference between the real atrium obtained with PhotoScan and the simplified atrium made with AutoCaD.

The same model was used for the analysis by means of discrete elements, since the simplification made for the photoelastic model (in the given scale) also complied with the limitations of the DEM methodology used (Fig. 6(a) 6(b)) [19].



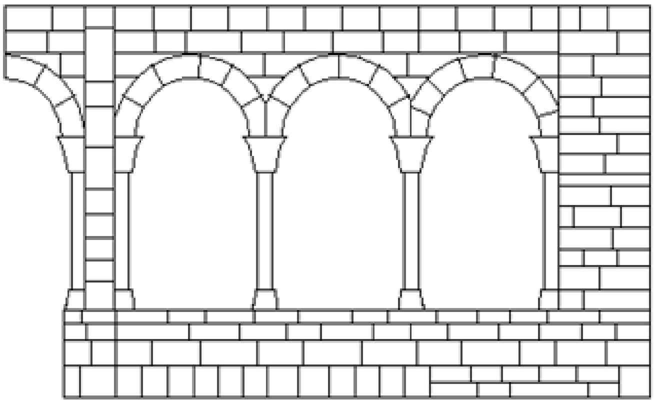


Figure 6 (a). Atrium resin model. Figure 6 (b). Simplified atrium model used in DEM.

The analysis using finite elements method required a specific model of much more complexity, given that the analysis software (AutoFEM Analysis 2.9) is designed to study continuous media.

Its application to discontinuous media requires the design of a constituent element that can incorporate correct contour conditions allowing the implementation of randomness in the supports coherent with reality.

It started, in this case, of the simplification developed for the DEM model. The necessary corrections to make the FEM model conform to the requirements of the program were made, in this case, manually (Fig. 7).

This would not have been necessary if we wanted to study the section as a continuum, but this type of approach is meaningless for the analysis of this type of historical structure [20].

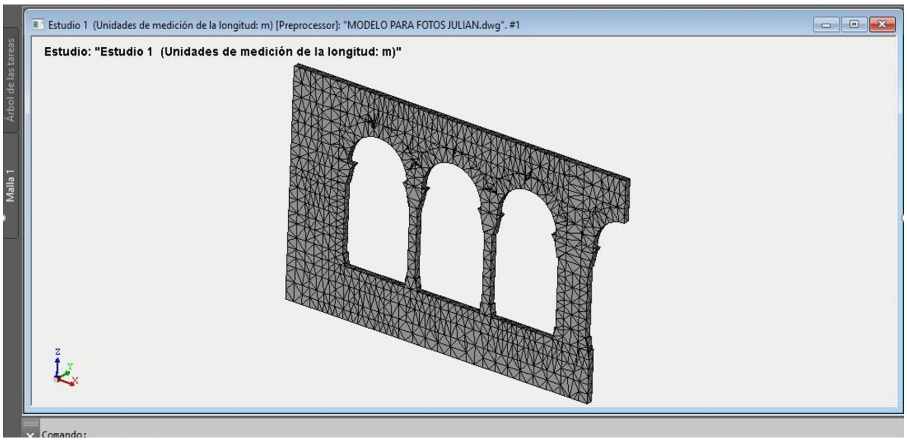


Figure 7 FEM model used in AutoFEM Analysis 2.9 software.

3. CONCLUSIONS

The use of photogrammetry allows to determine the exact geometry and position of the masonry elements that makes up a historic wall when they are seen outdoors. To obtain a detailed orthophoto of an element at a scale of 1: 1, we only need to have a photographic device with an average quality (although even the tests carried out with mobile phone cameras have given quite good results), a small sketch and some points measured as reference.

This system permits a quick initial uptake of a historic wall with a very low cost, which can be very useful in the early stages of an intervention or survey.

The quick processing of the geometric data is feasible when we need to adapt them to the requirements of the different stability analysis methods. However, it must be done with full control of the simplifications inherent to the adaptation process.

The combination of these detection systems with the analysis methods can be of great interest in cases in which we need a quick survey, such as accidents, emergency situations or natural catastrophes.

In addition, the real plans obtained with the photogrammetry of San Millán de Segovia were used to create the adapted models showed in the figure 5. They were included in a Master's Final Project [18] in order to apply them in Photoelasticity tests. This practical method permits a very visual and didactical approach to masonry structural behavior.

4. REFERENCES

[1] Wittmann, W. "Zur Theorie Der Gewölbe". Zeitschrift Für Bauwesen (29), pp. 61-74, 1879.

[2] Block, P., Ciblac T, Ochsendorf JA. "Real-time limit analysis of vaulted masonry buildings. Comput Struct 84, pp. 1841-1852

[3] Mark, R. "Experiments in Gothic structure". MIT Press (1984)

[4] Montañés, J.M.R., "Enciclopedia del Románico de Castilla y León," Segovia, Vol. III, , Ed. Fundación Santa María la Real, Centro de estudios del románico, 2002, pp. 1456-1480.

[5] Torres Balbás, L. "Restos de una techumbre de carpintería musulmana en la iglesia de San Millán de Segovia". Al-Ándalus, v. III; pp. 424-434. ISSN 0304-4335

[6] Nuere, E. "Una hipótesis sobre la techumbre de San Millán de Segovia". Estudios Segovianos nº 89. 1992

[7] Fuentes González, P. (2013). "Bóvedas de arcos entrecruzados entre los siglos X y XVI. Geometría, construcción y estabilidad". Tesis (Doctoral), UPM.

[8] Merino de Cáceres, J.M, "La torre de la iglesia de San Millán de Segovia y su construcción," IEEE Actas del cuarto congreso nacional historia de la construcción, , pp. 27-29, 2005.

[9] Dodero, F.J.C., "Conservación de los monumentos de Segovia (1938-1952)", Revista Arte Español, Spain.

[10] Gil, A.G. "Notas sobre la arquitectura restaurada de San Millán", Spain, 1977.

[11] Geobit. PhotoScan software, 2006.
Available: http://www.agisoft.es/products/agisoft-photoscan/

[12] AutoCad v. 2014. Autodesk.
Available: https://www.autodesk.es/products/autocad/overview

[13] Visual computing laboratory. Meshlab software.
Available: http://www.meshlab.net/

[14] Bigoni, G.N.D. "Localized stress percolation through dry masonry walls". European Journals of Mechanics, 2009.

[15] Huerta Fernández, Santiago. "Mechanics of masonry vaults: The equilibrium approach." (2001): 47-69.

[16] Riveiro, B., Morer, P., Arias, P., y de Arteaga, I. 2011."Terrestrial Laser Scanning y Limit Analysis of Masonry Arch Bridges". Construction and Building Materials 25 (4): 1726-1735.

[17] Rajchenbach, J. "Stress Transmission trough a cohesionless material". Mater. Phys. Mech. 3 (2001).

[18] Guerra, M.. "Iglesia de San Millán de Segovia. Historia constructiva y ensayos fotoelásticos". Master's final project, Madrid, Escuela Técnica Superior de Arquitectura, Universidad Politécnica de Madrid. Spain, 2017.

[19] Magdalena, García, J., Mencías, D. "Estructuras de fábrica: enfoques antiguos y modernos para fenómenos muy locales", Informes de la construcción, vol. 68, , pp. 1-8, Spain, april-june 2016.
Available: https:// doi: http://dx.doi.org/10.3989/ic.16.032.

[20] Magdalena, F., Aznar, A., Hernando, J.I. y García, J. "Linear programming as a tool to study the stability of masonry arch bridges", IABSE Madrid Symposium: Engineering for Progress, Nature and People, pp. 396-400, Spain, 2014.
Available: https://doi.org/10.2749/222137814814027927

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