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To cite this article: João Duarte *et al* 2021 *IOP Conf. Ser.: Earth Environ. Sci.* **906** 012015

IOP Conf. Series: Earth and Environmental Science **906** (2021) 012015 doi:10.1088/1755-1315/906/1/012015

Use of geotechnologies in mining planning in Quarries carbonated rocks - Contribution to the digital transition (Industry 4.0)

João Duarte[1], Francisco Sousa[2], Bruno Valente[3]

[1]IQGeo - Serviços, Lda e Geosciences Center of the University of Coimbra, Portugal
[2]Portugal, Portugal
[3]StillMoving, Lda, Portugal

joao.aduarte@iqgeo.pt

Abstract. As part of the strategy for Industry 4.0, this work was developed to outline a methodology that is an important contribution to improve the efficiency and productivity of processes in the ornamental stone extraction industry. Since this sector is important for the Portuguese economy, it is imperative to optimize processes to improve their efficiency in the use of resources, economic valuation, and economic viability. Knowing that one of the main factors to take into account in the feasibility of an exploration of ornamental rocks is the density, persistence and attitude of the discontinuities present in the rock mass, a methodology is proposed that aims to map and characterize the existing discontinuities in the using the latest digital technologies and whenever possible open access (CloudCompare, Stereonet, 3D Block Expert). To this end, work was initially carried out on an active exploration front, identifying and characterizing, through the traditional method (compass and clinometer) and photogrammetry, existing discontinuities and statistically analysing their occurrence. The data analysis shows a variation in the attitude of the discontinuities in a range of -17.72 ° to 14.7 °, this variation corresponding to the strike. As a percentage, there is also a variation in the range of values, from -5.30% to 4.91%, with the reference value being the value obtained by the photogrammetric method. This step was also used to compare the acquired data and verify the variations between them depending on the method used. Photogrammetry was used with another complementary purpose, but very important for the proposed methodology, which is related to the 3D modelling of the fronts and the subsequent projection or extraction of the existing discontinuity plans. The determination of the attitude of the discontinuities was obtained through the manipulation of the point clouds obtained by the photogrammetric modelling, based on the technique of Structure for Motion [SfM] and application of the RANSAC Shape Detection algorithm of the CloudCompare® program, which allows the determination of the attitude of the discontinuities. The characterization of the discontinuities by the photogrammetric method provided the data that was used in the present study to calculate the blocometry in that sector. This was calculated using the 3D BlockExpert software, based on the exploration sequences. The program calculated the predicted volumes in each one, based on a standard dimension for the block of 2.7 x 3.0 x 2.0 meters. As a result, it was possible to compare a number of blocks the value predicted by the 449 modellings and the number of blocks produced 490. This difference of approximately 10% for this order of magnitude is acceptable and confirms the reliability of the proposed methodology. This evaluation using Geotechnologies allows data modelling to be effectively an important process in the planning of the extractive process, and with the development of this approach, it may introduce in a second phase the decision automation of the extractive process, based on economic and commercial criteria and last and third stage, the automation of the extractive process.

1. Introduction

Industry 4.0 is a strategic initiative recently, whose objective is the transformation of the productive industry using the potential of new technologies for this purpose, improving the efficiency and productivity of processes [1].

In sectors of economic activity in Portugal as important as the extractive industry, namely in the ornamental stones sector, which is 2019 generated a wealth of 34% of the value of 170 278 (103 €) of the value of the production of Construction Minerals [2] and more than 16,000 direct jobs. It is imperative given the particularity of this sector that the optimization of processes is a condition for improving their efficiency.

The application of geotechnologies in this context, aims at the geological-structural characterization of the site [3], [4] and its influence on the process of characterization and planning of exploration [5], thus optimizing the entire process that leads to improve the use of the resource, with consequently less waste production and its economic viability. This approach is pertinent given that one of the main factors to consider in rock masses for the exploitation of ornamental rocks is the density, persistence, and attitude of the discontinuities present.

The method used has the objective of mapping and characterizing the discontinuities existing at the site, using the photogrammetric method [6], [7], [8]. To assess the accuracy of the proposed method, a comparison was made with the traditional method of acquiring geological-structural data (compass and clinometer).

After this analysis, data from the characterization of the discontinuities by the technological method were used for the present study, which was subsequently the target of geostatistical analysis and used in the calculation of blocometry in that sector [7]. The methodology employed uses recent technological methods, which allow to assist and optimize the data acquisition process, using, whenever possible in the processing and treatment of the data, freeware computer programs (CloudCompare, Stereonet, 3D Block Expert) being in line with process optimization. that allows a better cost / benefit ratio.

This evaluation using Geotechnologies allows data modelling to be effectively an important process in the planning of the extractive process and with the development of this approach introducing in a second phase the decision automation of the extractive process, based on economic and commercial criteria and the last and third phase, the automation of the extractive process.

2. Location and Geology

The present work was carried out in the quarry of the company Filstone SA., Located in the vicinity of Casal Farto, which is located approximately 7 km a southwest of the parish of Fátima, municipality of Ourém, district of Santarém, and 128 km from Lisbon.

Geologically, at the study site, lithologies belonging to the Serra de Aire Formation, known as Oolithic Limestones of Fátima (J^2_{FA}), are identified on sheet 27-A Vila Nova de Ourém [9], which form a crescent-shaped area, with the convexity for southwest, which extends from a little southwest of Cova da Iría to Bairro. These limestones constitute a lenticular unit within the micritic limestones of Serra de Aire (J^2_{SA}), but in this case, beveling from east to west. These limestones are presented as oo / bio / intra / pelsparites "grainstone" to "rudstone", rarely "pack-grainstones" usually define metric thickness layers, sometimes interspersed with less thick discontinuous levels of "packstone" biopelintramicrites. Also, characteristic of this unit is frequent levels of coarse granulometry, very rich in bioclasts [10].

3. Methods and methodologies

The acquisition of data on the fronts of the exploration in a first phase was carried out in two different ways, a fact necessary to assess the degree of confidence of each of the proposed methods and in particular the photogrammetric method. This procedure was necessary for the validation of the technological method, which must be used according to the guidelines implicit in the digital transition (Industry 4.0). The methodology initially proposed for the assessment of the degree of confidence and precision for the determination and characterization of the discontinuities present, compared the results of the data acquisition by the classical route (Compass and clinometer) and photogrammetric survey, according to the flowchart shown in figure 1. With the degree of confidence and precision measured, the data acquired by the photogrammetric method were used to identify, characterize and model (3D) the discontinuities (Strike, dip and persistence), according to the flow charts shown in figure 2.

It is important to note that this flowchart is the idealized flowchart to achieve the proposed objectives for the implementation of the digital transition (Industry 4.0) in this sector of industrial activity. The last step, the Extraction planning decision, not developed in this work, but will have to be integrated into the procedures in the future.

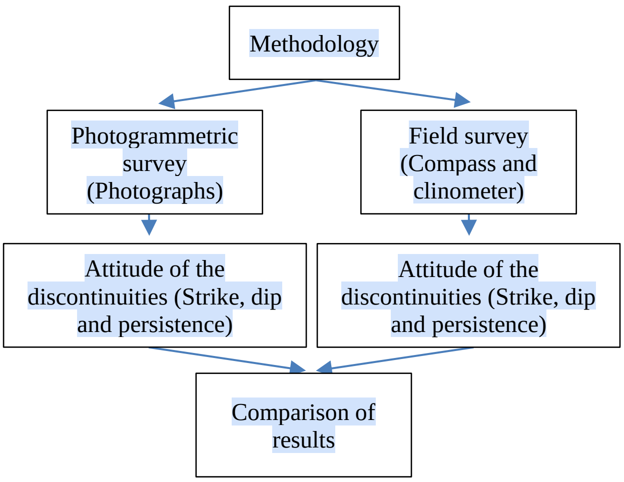

Figure 1. Methodology to measure the best method

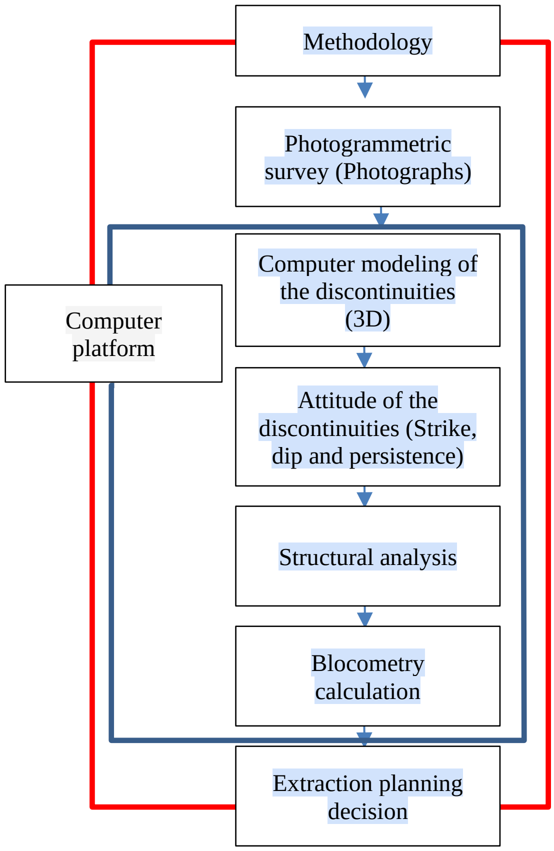

Figure 2. Methodology to be used in the process. Blue line 1st phase. Red line 2nd phase

Data acquisition was carried out on fronts of active mines, observing the progression of the extractive process (Figure 3). During this process, field measurements were made (compass and clinometer and photographs of the fronts were used, using a camera with the characteristics described in table 1, which were subsequently processed to create a 3D photogrammetric model using the Agisoft Photoscan program [11] (Figure 4).

Figure 3. Aspect of the exploration front targeted for study

Table 1. Camera Technical Specifications

Brand:	Canon
Model:	EOS 1100D
Effective megapixels:	12.20
Sensor size:	22.2 x 14.8 mm
Sensor type:	CMOS
Sensor resolution:	4278 x 2852
Max. image resolution:	4272 x 2848
Focal length:	18 mm
Crop factor:	1.62
ISO:	Auto, 100, 200, 400, 800, 1600, 3200, 6400

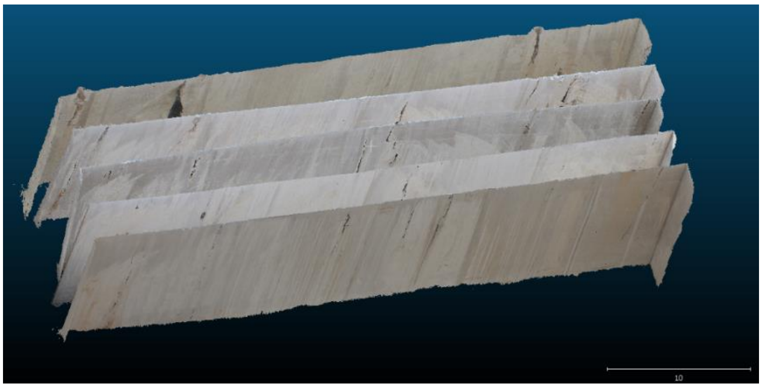

Figure 4. 3D photogrammetric model of extractive fronts.

The statistical treatment of the acquired data was carried out using the Stereonet 11 program, developed by Richard Allmendinger's, from Cornell University [12], with the plans defined by the technique projected in the rose diagram, thus being able to be statistically evaluated for their occurrence. For the structural analysis, the method proposed in the work presented by [13] was used, which determines the attitude of the discontinuities through the manipulation of point clouds obtained by photogrammetric modelling, based on the Structure for Motion [SfM] technique. The technique allows determinate an attitude discontinuity, through the application of the RANSAC Shape Detection algorithm of the CloudCompare® program [14]. In applying this method, it was decided to use the manual method of shape detection. A similar method was applied in Viana's work [15]. To characterize structures, the methods and methodologies presented in the works of Maconochie [16], Pate [17], Gates [18] and other bibliographies available on the Sirovision program website [19] were applied.

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The creation of 3D models where it was possible to visualize, project and determine the characteristics of the discontinuities was an essential tool to determine the degree of confidence and precision of the technological method about to with concerning to the others.

To visualize the compartmentalization of the massif through the segmentation of discontinuities, Dmitry Nikolayev [20] developed the 3D BlockExpert software. Through this application, it is possible to evaluate the distribution of discontinuities providing solutions for the distribution and extraction of blocks in situ, as well as the shapes and volumes obtained. This was the procedure adopted in the present work.

4. Results and discussions

The methodology used expects the usage of technological data for the evaluation of the rock properties. After the acquisition of the photogrammetric information, a 3D modelling of the exploration front identified as number 1 was carried out, based on the sequential images of the exploration 789, 802, 820, 835 and 848. The model obtained was subsequently manipulated to extract the existing discontinuity plans (Figure 5). At the same time, discontinuity data were acquired using the traditional method (compass and clinometer).

These plans were compared to measure the variation of values according to the method used (Table 2). The reference values are always those obtained by the photogrammetric method.

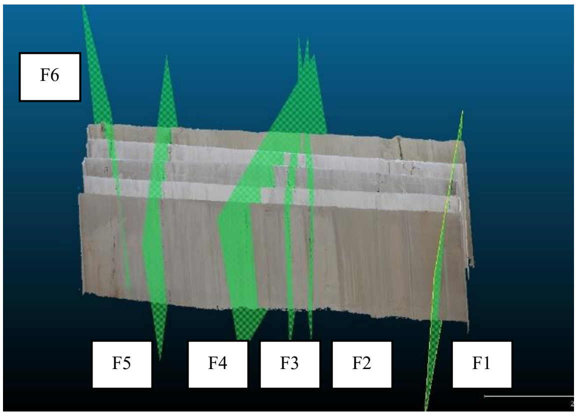

Figure 5. Manual detection of discontinuity planes in Cloud Compare

Table 2. Comparison table of the values of the attitudes of the discontinuities by the acquisition system

Discontinuity	Front number	Method		Difference		Discontinuity	Front number	Method		Difference	
		Compass	Photogrammetry	Compass/Photogrammetry				Compass	Photogrammetry	Compass/Photogrammetry	
		(°)	(°)	(°)	(%)*			(°)	(°)	(°)	(%)*
F1	789	310				F4	789	316			
	802	308					802	310			
	820	324					820	324			
	835	315					835	318			
	848	313					848	315			
	Average	314	315.20	-1.20	-0.38		Average	316.6	334.32	-17.72	-5.30
F2	789	314				F5	789	312			
	802	314					802	314			
	820	320					820	320			
	835	324					835	320			
	848	317					848	315			
	Average	317.8	303.44	14.36	4.73		Average	316.2	314.65	1.55	0.49
F3	789	320				F6	789	308			
	802	312					802	308			
	820	318					820	322			
	835	320					835	318			
	848	318					848	315			
	Average	317.6	314.00	3.60	1.15		Average	314.2	299.50	14.70	4.91

Note *: The value presented is based on photogrammetry (100%).

In the 3D model, 6 planes were identified (F1, F2, F3, F4, F5 and F6), from which the attitudes were extracted. These plans correspond to the plan that intercepts the various fronts on the site. The values of the attitude of the discontinuities obtained by the traditional method (Compass and clinometer) were obtained face to face and later the average value of the various measurements was calculated.

Analyzing the table, there is a variation in the attitude of the discontinuities in a range of -17.72 ° to 14.7 °. As a percentage, there is also a variation in the range of values, from -5.30% to 4.91%, with the reference value being the value obtained by the photogrammetric method. This variation in the direction values is partly due to deficient sampling, which can vary due to poor positioning of the compass, a condition that is expected in such an environment. The photogrammetric process is more reliable since it does not depend on the way of acquiring the attitude, the manual positioning of the compass, but it can, however, depend on the way of acquiring the photography. This depends on several factors such as resolution, brightness, the condition of the fronts, but always less likely to cause marked variability in the acquired values. The next step was the statistical evaluation of the values obtained, for that purpose the rose diagram is the best option. The statistical projection in the rose diagram of the values obtained by the traditional method is represented in figure 6 and those obtained by the photogrammetric method are represented in figure 7.

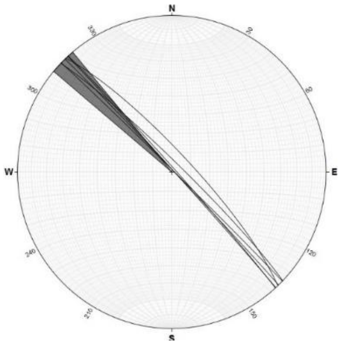

Figure 6. Representation of discontinuities in the rose diagram. Compass and clinometer

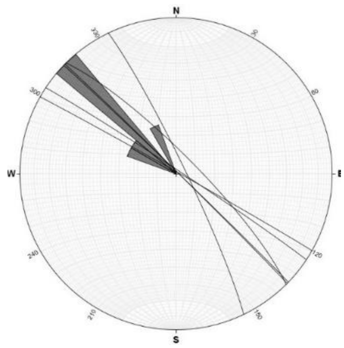

Figure 7. Representation of discontinuities in the rose diagram. Photogrammetry

From the analysis of the diagrams, there is an agreement with the orientation of the discontinuities and with the Dip. However, the strike values have variations depending on the acquisition method. In the traditional method (Compass and clinometer) the maximum value of 100% of the occurrences are between 311 ° and 320 °. The average vector, which has only statistical significance, is located at 316.1 ° ± 02.3°. As for the values obtained by the photogrammetry method, it has a maximum value of 50% of the occurrences between 311 ° and 320 °. The average vector, which has only statistical significance, is located at 313.3 ° ± 09.5 °. Based on the values obtained from the attitude of the discontinuities, blocometry was calculated using the 3D BlockExpert software. In this case, the photogrammetric model corresponding to each sequence was superimposed with the image generated by the program, to check the correspondences (Figures 8-11). The values of the attitudes of the discontinuities used were those obtained by the photogrammetric process. Of the total volume corresponding to the front considered (No. 1), 2041.2 m3 per sequence, the volumes predicted by the modelling (Table 3) were calculated, using a standard dimension for the block of 2.7 x 3.0 x 2.0 meters. The value considered as remaining corresponds to the dimension value of the blocks that do not have the standard measure defined.

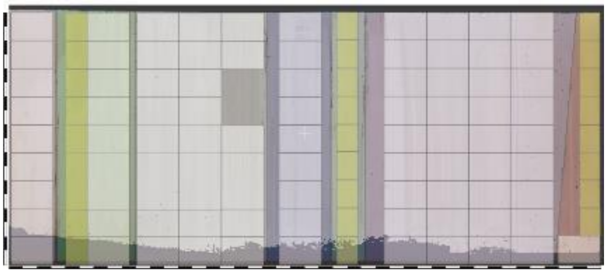

Figure 8. Overlap of the photogrammetric model with the image obtained by the program 3D BlockExpert. Sequence 789.

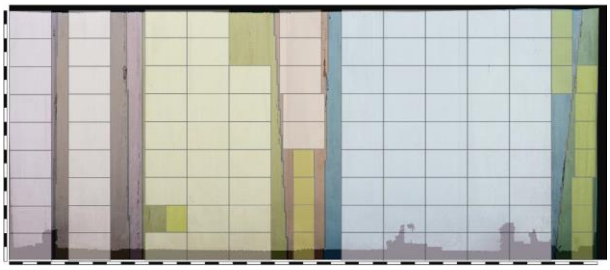

Figure 9. Overlap of the photogrammetric model with the image obtained by the program 3D BlockExpert.Sequence 802.

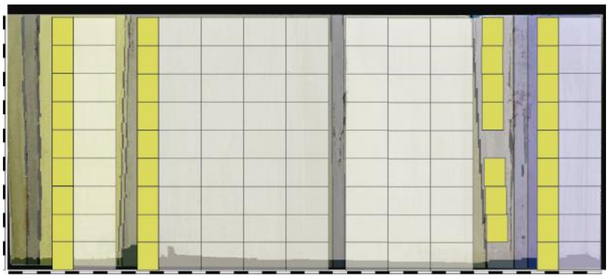

Figure 10. Overlap of the photogrammetric model with the image obtained by the program 3D BlockExpert. Sequence 835.

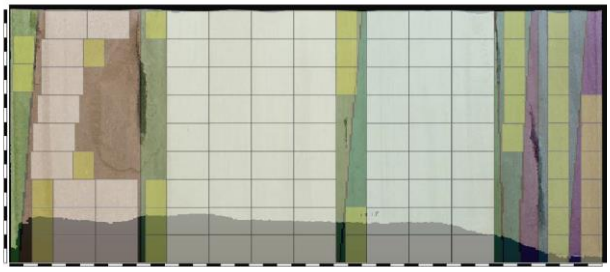

Figure 11. Overlap of the photogrammetric model with the image obtained by the program 3D BlockExpert. Sequence 848.

Table 3. Table of volumes calculated by the program.

Nº Sequence	Front volume (m^3)	Calculated volume (m^3)	Calculated remaining volume (m^3)
789	2041,2	1981	60,2
802	2041,2	1975,8	65,9
835	2041,2	1956,2	84,8
848	2041,2	1951,4	89,8

In the end, the number of predictable blocks of rock to be obtained was calculated and compared to the actual number the company obtained (Table 4).

Table 4. Comparison of the number of estimated and actual blocks.

Nº Sequence	789	802	835	848	Total expected	Total real
Nº Blocks	115	107	115	112	449	490

Comparing the values referring to the location, it can be seen that the estimated value decreases sequentially. This fact is because since the discontinuity plans are decreasing the distance between them in the direction of the advancement of exploration. Therefore, taking into account the defined block size, this increase does not correspond to the acceptable value for calculating the volumes. To counteract this, the technique would be to reprocess the data with a smaller standard size. Unfortunately, no production volume figures have been made available to validate the estimated volume.

However, data were provided on the number of blocks produced, in which the number of real blocks exceeded the theoretical value obtained by a difference of 41 blocks where in a comparison of values of this order of magnitude, the margin of error can be considered acceptable (Approx. 10%), which may be related to the use of blocks with dimensions smaller than the standard dimension used.

5. Conclusions

The proposed methodology allows for a quick, convenient, and inexpensive way to identify and characterize the attitude of the discontinuities present in the exploration front. Associated with the program that determines the blocking based on the data acquired in the previous phase and described in the work, it is possible to anticipate the volume and number of units that may result from the extractive process, as has been evidenced. Another advantage is the possibility for the decision-maker to plan and define exploration strategies considering commercial and economic factors. The process, which is semi-automatic and in stages, must be fully automatic in the future, with digital interfaces that obtain the data acquisition, proceed to the structural characterization of the rock mass (roughness, classification of discontinuities, humidity, slope) and the calculation of blocometry, making them available and storing them on a digital platform. In this way, the decision-maker has access to the available information at any location and the possibility to quickly define the best exploration planning strategy. These decision steps soon, as already mentioned, should also be automatic on the platform as well as the subsequent process. The automatic extraction processes.

For the automation process to be complete, the acquisition of photogrammetric data will have to be adapted to the use of UAV's (Unmanned Aerial Vehicles), which can be programmed to perform tasks as well as remotely manipulated.

The reliability of the acquisition and the results obtained can be increased by using other methods adapted to the proposed methodology. As expected, the resolution of the model is a function of the characteristics of the sensor used, the acquisition conditions (brightness, contrast, characteristics of the fronts) since it is a photogrammetric process. One of the most viable solutions is the use of the Laser Scanner, which allows a better resolution in conditions that are adverse to the photographic process. However, there is a limitation of visualization of the point cloud produced by the acquisition of data by this method, which can be bridged and textured with a photogrammetric survey.

Acknowledgment(s)

To IQGeo-Serviços, Lda for the financial, material, and human investment, to Filstone S.A. for allowing the use of the facilities and industrial. We thank FCT-MEC for its financial support through national funds and, when applicable, co-financed by the ERDF within the PT2020 partnership, through the research projects UID/Multi/00073/2020 of the Geosciences Centre and UID/Multi/00308/2020.

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