OPTIMIZING THE EXPLOITATION OF ORNAMENTAL ROCK QUARRIES BY ANALYSING THE FRACTURE NETWORK

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Abstract. Within the ERA-MIN project: Artificial Intelligence and Combined Survey Techniques for Stone Quarries Optimization (AI-COSTSQO acronym), a decision support system (DSS) was developed based on computerized expert systems, artificial intelligence (AI), as well as other algorithms, which could include multi-criteria methods and analytic hierarchy process (AHP).
This system (DSS) included: generating block size distribution curves (BSDC), determining minimum and maximum limits of cuboids and trading volumes as well as establishing a set of rules for trading decisions, finding maximum cuboids from irregular polyhedral (MaxQ), 3D Graphics Representation of Blocks and Mapping/Contouring, Digital Elevation Models (DEM) from Point Clouds and Discrete Fracture Networks (DFNs) and In-situ Field Investigation, which represented the basis for the realization of the components of (DSS).

Keywords: Marble Quarry, Investigation Methods, Artificial Intelligence, Discrete Fracture Networks (DFNs), block size distribution curves (BSDC).

Rezumat. Optimizarea exploatării carierelor de rocă ornamentală prin analiza rețelei de fracturi. În cadrul proiectului ERA-MIN: Artificial Intelligence and Combined Survey Techniques for Stone Quarries Optimization (acronim AI-COSTSQO), a fost dezvoltat un sistem de suport decizional (DSS) bazat pe sisteme expert computerizate, inteligență artificială (AI), precum și alți algoritmi, care ar putea include metode cu mai multe criterii și procese de ierarhizare analitică (AHP). Acest sistem (DSS) a inclus: generarea de curbe de distribuție a dimensiunilor blocurilor (BSDC), determinarea limitelor minime și maxime de cuboizi și volume de tranzacționare, precum și stabilirea unui set de reguli pentru deciziile de tranzacționare, găsirea de cuboizi maximi din poliedri neregulați (MaxQ), grafică 3D Reprezentarea blocurilor și cartografierea/conturarea, modelele digitale de elevație (DEM) din nori de puncte și rețele de fracturi discrete (DFNs) și investigații în teren in situ, care au reprezentat baza realizării componentelor (DSS).

Cuvinte cheie: Cariera de marmură, metode de investigare, inteligență artificială, rețele de fracturi discrete (DFN), curbe de distribuție a dimensiunii blocurilor (BSDC).

INTRODUCTION

Stone blocks, such as marble, granite, sandstone, travertine, and other ornamental stones, are natural materials with excellent properties. They are widely used in a variety of industries, primarily constructions. However, their exploitation while operated in quarries is strongly conditioned by unavoidable fractures and discontinuities. These include faults, joints, bedding planes, shear zones, fissures and micro-cracks. These defects are entirely natural, yet they preclude the extraction of larger, entire blocks of much greater commercial value, which means that the presence of such structural defects must be evaluated at every stage of the production in terms of presence, frequency and spatial positions. This natural condition presents a considerable challenge for production, increases costs and poses environmental risks. In this work, we make a brief presentation of the work stages within the ERA-MIN project, acronym AI-COSTSQO. The theoretical considerations that were the basis of this project can be found in the selected biography (TURANBOY & ULKER, 2008; 2009; 2014).

METHODOLOGIES AND RESULTS

The first work package (WP) included on-site field measurements to characterize the rock mass in terms of joints, fractures, discontinuities. The types of measurements were:

- **Ground Penetrating Radar (GPR)**, measuring in the selected testing sites of Romania, Italy and Turkey. This is a proven technology to identify discontinuities and fractures.

An example for 4 GPR profiles in the Carpinis quarry is given in Fig. 1, where one can see the main fractures and crack zone. The equipment used in the field measurements was AKULA 9000C and two antennas FLB 390 and GCB 200. The software supplied with the Akula 9000C radar control units is universal for all Geoscanner control units, making switching between control units simple and quick. To obtain a 3D block diagram with fracture interpretation, GPRSoft™ Professional software is required. FLB antennas have a relatively small footprint on the air-ground interface, given that they operate in the VHF band, and therefore a substantial amount of power is successfully delivered to the ground. GCB antennas have the best performance in their antenna category on the market and are fully shielded, providing excellent results in even the most polluted EM survey sites. The software used in the complex processing that is exemplified below was Prism 2. In the figures below, the profiles processed at the Carpinis quarry are exemplified, where the main fractures and the fracturing zones are shown.

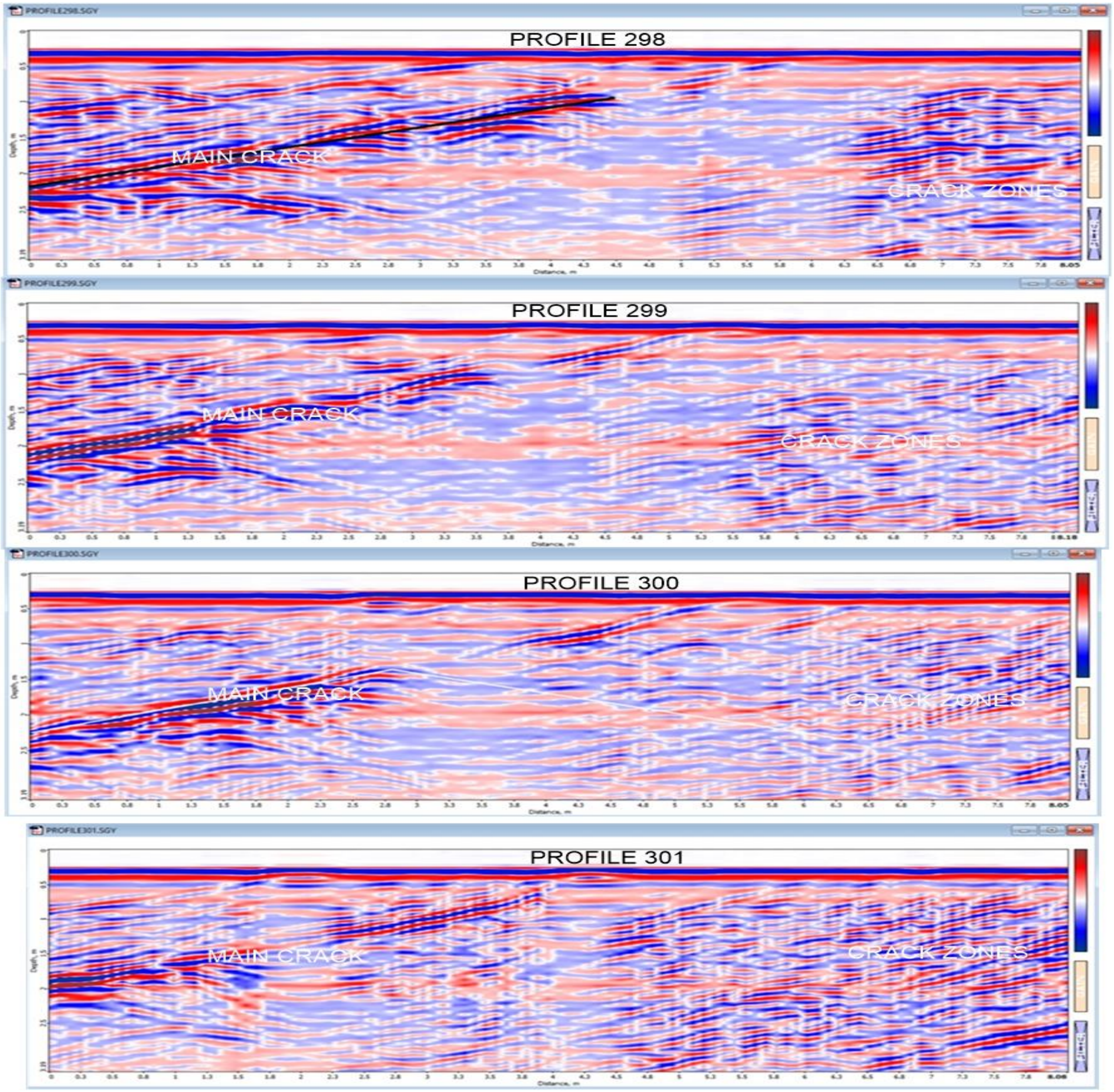

Figure 1. Profiles 298-301 at the Carpinis quarry.

- The classical geological mapping of the quarry bench used jointly with the GPR survey to validate and integrate the results of the GPR survey.

- Structural information from Televiewer to get images of the holes for later reconstruction of the presence of fractures, joints and faults in terms of inclination, orientation (dip/ dip direction, trend/ plunge).

- **Ground Investigation using Seismic Refraction** used in the selected case studies to integrate with the other measurements and provide more information.

An example for seismic profiles in the Ruschita quarry is given in Fig. 2.

Seismic measurements performed at quarries in Romania used the Geode-Seismograph system with 24 channels, and the interpretation was done with the SeisImager software.

- **Ground Investigation using Electrical Resistivity** was applied for rock characterization. This method will be used at the selected testing sites to characterize the rock mass and measure Rock mass quality.

Figs. 3 - 4 include the profiles at the Pietroasa quarry and 3D interpretation. The areas of minimum, outlined in blue, represent fractures and fissures in the quarry rock mass. Also, the areas of increased gradient (quick transitions from minimum-blue to maximum-red) highlight the change in the geological and microtectonic characteristics of the rock mass.

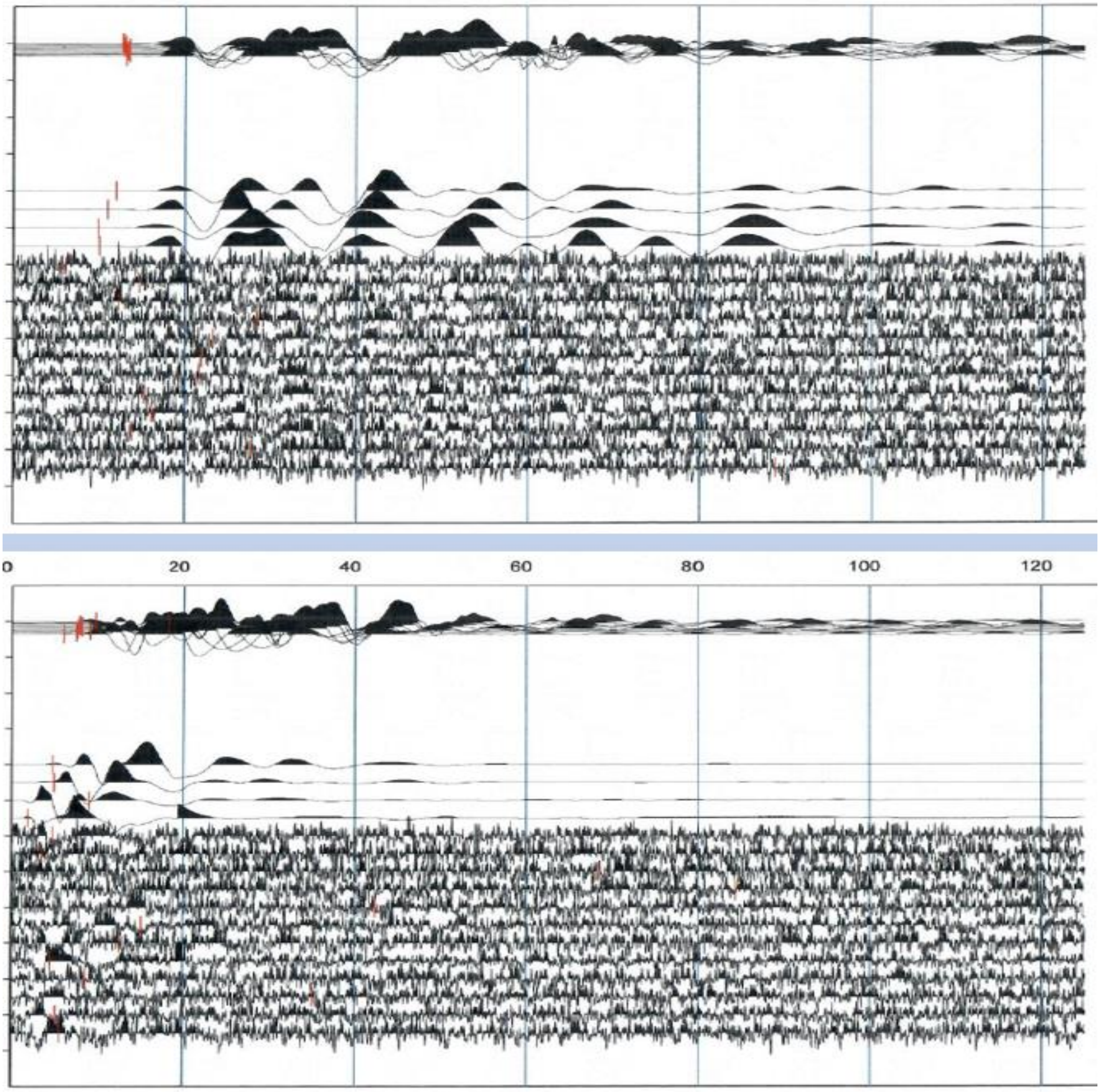

Figure 2. Seismic profiles at the Ruschita quarry.

The used equipment, the SuperSting R8/IP+64 system, is produced by the American company Advanced Geosciences, Inc, Austin, Texas and uses a pulsating direct current for emission, with the duration of the pulse equal to the duration of the pause. Compensation of the natural potential is done automatically, throughout the measurement. Resistivity is calculated by entering the coordinates of the device, so that the system can generate images of resistivity and induced polarization uses the EarthImager software. The acquisition system has 8 channels and is used with multi-electrode passive leads. T

he second WP included Digital Elevation Models (DEM) from Point Clouds and Discrete Fracture Networks (DFNs) from which to extract discontinuity parameters (dip, dip direction and persistence/trace length). From the derivation of DFN, which will be validated against field data, a computer program was developed to generate stochastic DFNs.

In WPs 3 and 4 a consistent end-to-end architecture was provided for generating the 3D Graphics Representation of Blocks and Mapping/Contouring and Finding Maximum Cuboids from Irregular Polyhedrons.

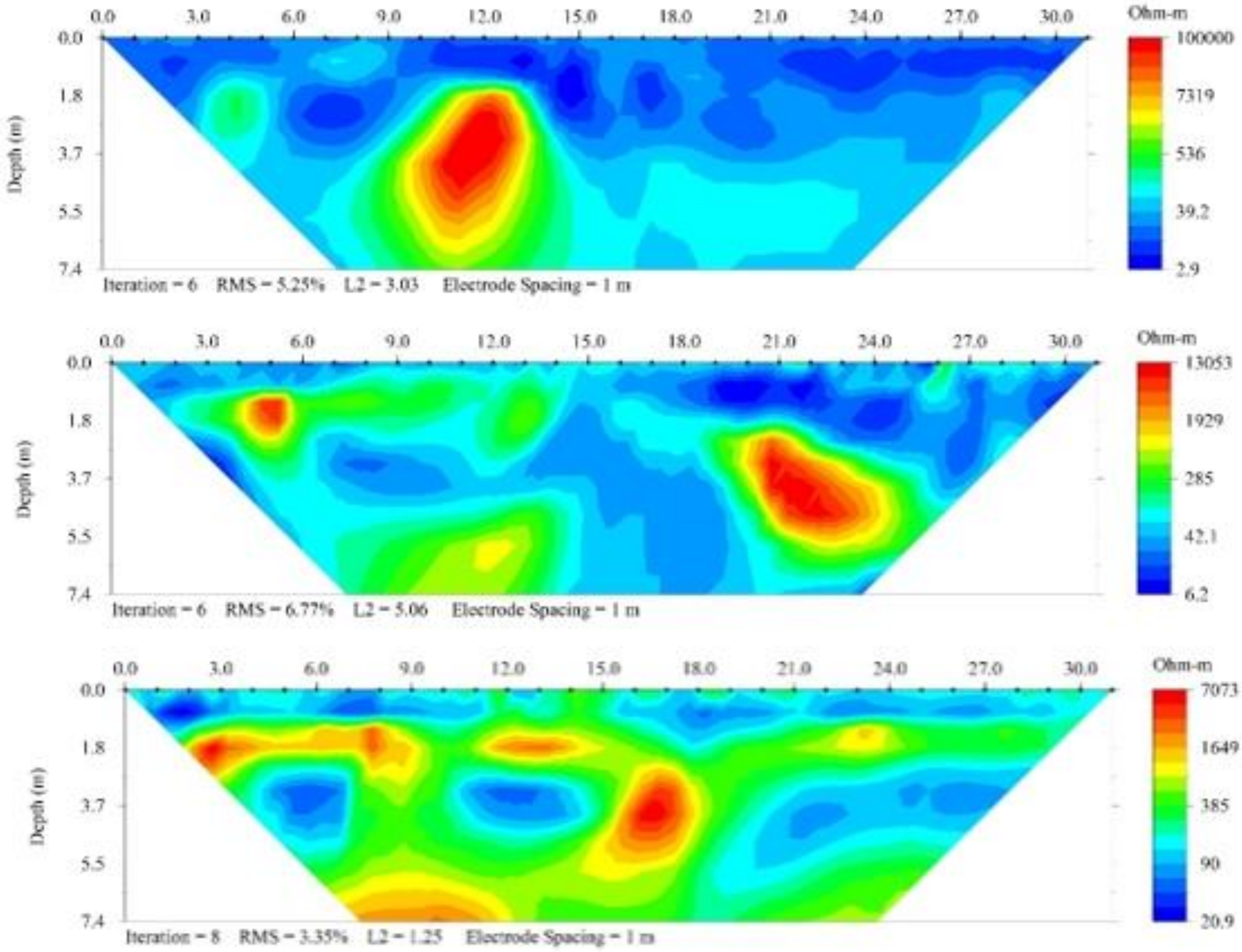

Figure 3. Electrical Resistivity profiles at the Pietroasa quarry.

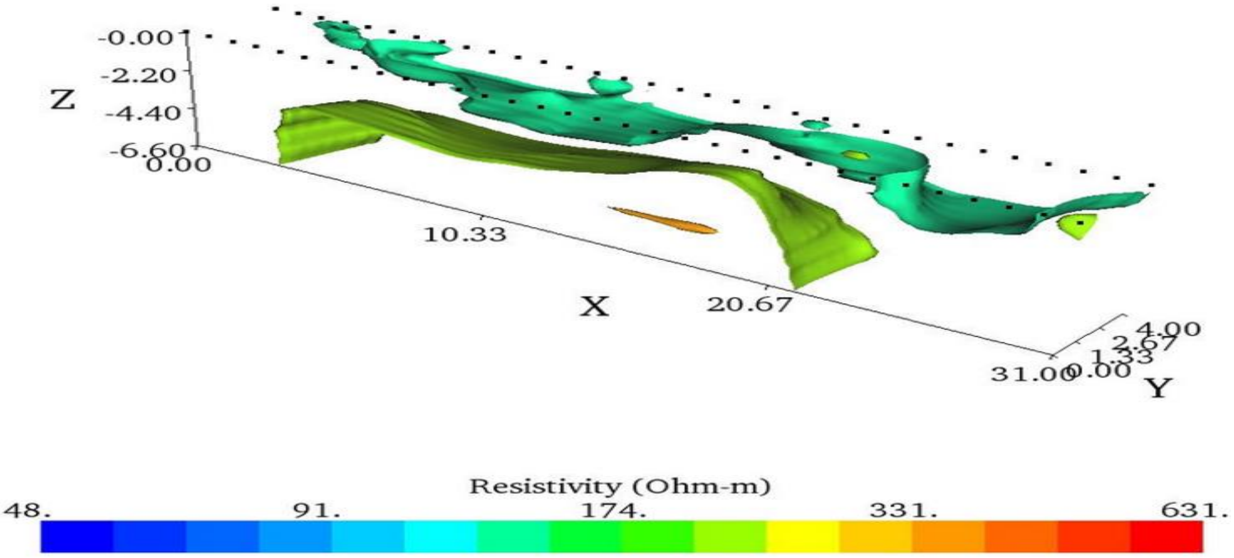

Figure 4. 3D Resistivity Contour Plot of Electrical profiles at the Pietroasa quarry.

In Fig. 5 are Dynamic Slices of Inverted Resistivity at the Pietroasa quarry, made based on measurements on the resistivity profiles.

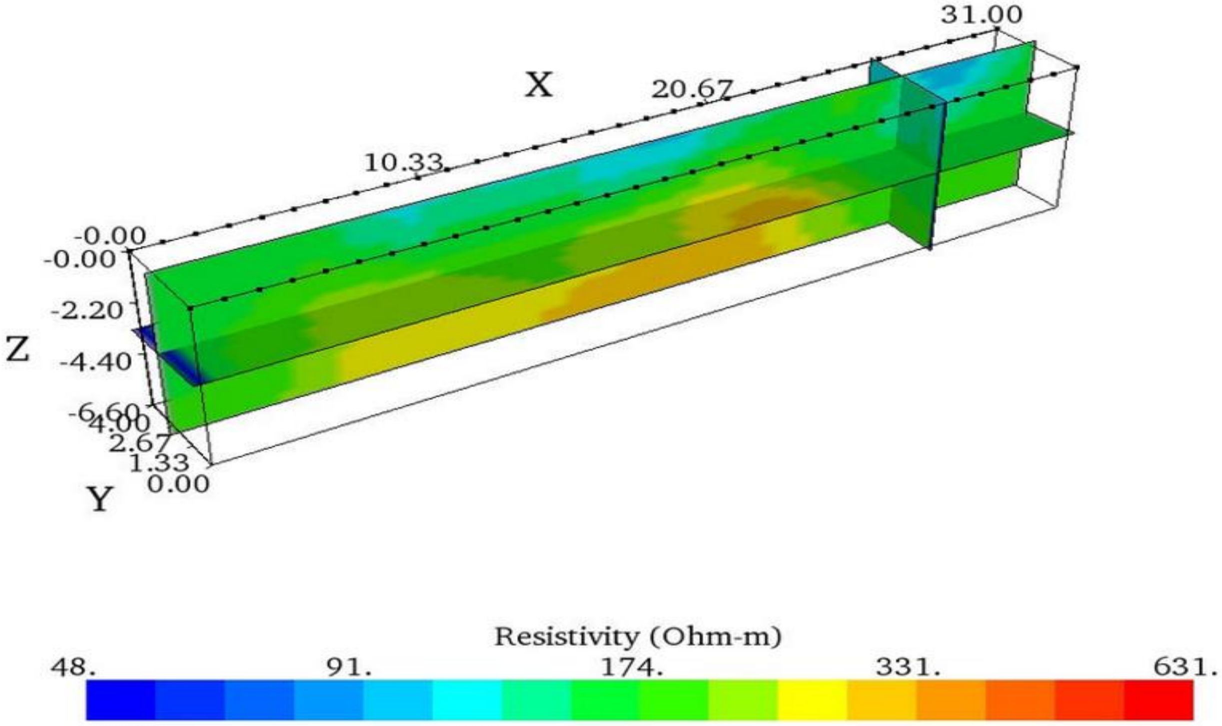

Figure 5. Dynamic Slices of Inverted Resistivity at the Pietroasa quarry.

The objectives in WP 5 were to use as data input the results of WP1-WP4. Both polyhedrons and MaxQs were visualized in a single graph. These data were displayed together as three separate curves for on-site, theoretical, and real cuboids obtained from run-of-mine production in the quarry. A decision support system in the form of a rule-based expert system was developed to interpret the graphic. To realize DSS, multi-criteria search engines were included with the generation of reports, and the proposal of optimal solutions on the project website [www.] was the basis of the studies on the evaluation of the excavation directions of the quarry, the location and dimensions of the quarry to be operated to a virgin reserve, and the assessment of an actual quarry in terms of efficiency. DSS was developed based on computer Expert Systems, Artificial Intelligence (AI), as well as other algorithms. For generating BDSC – the best way to characterize the block size, representative block volumes (25, 50 and 75%) should be obtained from rock mass with a methodology to characterize the rock mass and generate BSDC.

Based on the DFN model, the size of the blocks and their distribution are calculated. Thus, the influence of the size of the rock blocks on the integrity and mechanical properties of the rock masses in the quarry is evaluated. The spatial distribution of the blocks consists of sets of discontinuous joints. With increasing discontinuous merge sets, however, the Block Size Distribution Curves (BSDC) will obviously change and the block size will decrease. The quality of the rock mass is a very important parameter that could influence the volume of the blocks and their distribution. BSDC depends on fracture parameters such as joint set orientation, joint spacing, number of joint sets, and persistence. The rock mass consists of main fractures and fractured zone (matrix), and blocks of various sizes are generated by their intersections. Fig. 2 shows the scheme of operations and their sequence.

For finding the Minimum and Maximum Boundaries of Commercial Cuboids and Volumes, we calculated the directions of cuttings in stone blocks regarding the Minimum and Maximum Boundaries of Commercial Cuboids and Volumes and existing natural joints and discontinuities. In addition, using the data obtained as a result of field applications, the quarry's location was taken into account for maximum quarry efficiency (for a virgin deposit).

The set of rules for commercial decisions was based on BSDC and the requirements of the beneficiaries (and several commercial standards). Other parameters (vein, texture) observed from the field surveys and which can affect the commercial value of natural stones were added to BSDC as new rules.

DSS was developed based on computer expert systems, Artificial Intelligence (AI), as well as other algorithms, which might include multi-criteria methods and Analytical Hierarchy Processes (AHP).

In the following WPs, Stone Quarries Optimization Software as a System (SaaS) is developed, which includes an Information System Table based on which, going through several stages, a Decision Support Systems Interface will emerge. One of the innovative aspects of AI-COSTSQO is the DSS (Decision Support Systems Interface). The final success is the generated AI-supported DSS.

In Fig. 6 is a diagram that exemplifies the procedure for calculating the block size and its effect on rock mass mechanical behaviors. This diagram is also detailed on the project website http://ai-costsqo-project.com/.

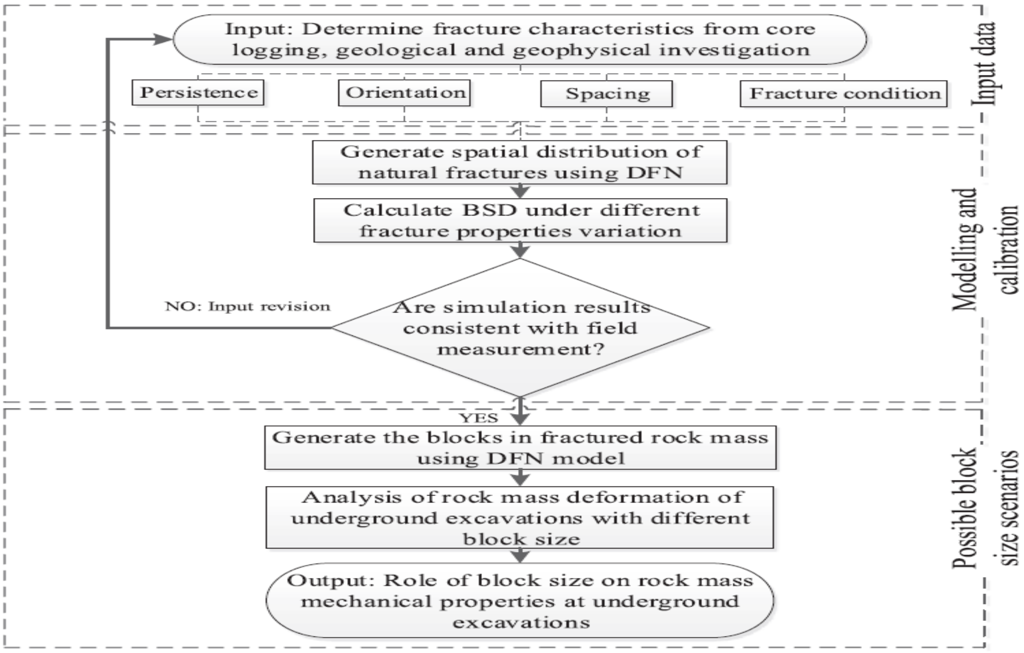

Figure 6. The procedure for calculating the block size and its effect on rock mass mechanical behaviour (after: WENLI et. al., 2020).

CONCLUSIONS

This paper explains how to achieve a sustainable and responsible supply of primary raw materials (block stones) and ensure the environment's optimal protection [http://ai-costsqo-project.com/].

The rock mass has many characteristics: discontinuity geometry, orientation, mechanical characteristics, colour and texture, that are technical and economic restrictions. In the quarry-planning processes, the blocks of stone need to be classified into two categories, as exploitable or non-exploitable, based on these characteristics. In our paper, we describe the solution for finding the maximum volume of cuboids that can be cut from any polyhedral block described in 3D by vertices and the model construction, a concept for the optimal exploitation of quarries.

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REFERENCES

TURANBOY & ULKER E. 2008. LIP-RM: an attempt at 3D visualization of in situ rock mass structures. *Computational Geosciences*. Springer Nature. Berlin. **12**: 181-192.

TURANBOY A. & ULKER E. 2009. Maximum volume cuboids for arbitrarily shaped in-situ rock blocks as determined by discontinuity analysis. A genetic algorithm approach. *Computers & Geosciences*. Elsevier. Amsterdam. **35**: 1470-1480.

TURANBOY A. & ULKER E. 2014. Using the distribution curves to optimize the block exploitation in natural stone quarries. In: Alejano, Perucho, Olalla & Jiménez (Eds.). *Rock Engineering and Rock Mechanics: Structures in and on Rock Masses*. Taylor & Francis Group. London. 115-124.

WENLI Y., SHARIFZADEH M., ZHEN Y. 2020. Assessment of block size distribution in fractured rock mass and its influence on rock mass mechanical behavior. *AIP Advances***.** **10**: 1-10.

***. http://ai-costsqo-project.com/ (accessed January 12, 2024).

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