



## **Close range photogrammetry for the analysis of unstable slopes in the Apuan Alps marble quarries (Carrara, Italy)**

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This paper describes the study of fractures and rock mass in the Carrara Marble District (Apuan Alps) for the exploitation and the evaluation of stability in quarries activities. Frequently, the hard accessibility of the walls of excavations does not allow direct measurements of discontinuities through the traditional geological methods. The digital terrestrial photogrammetry is a technique that can be used for a detailed survey especially in hardly accessible sites and from it oriented stereoisimages, accurate digital elevation models and orthophotos can be created; then, it can be used as data source for studying the rocky slope stability in marble quarries. Nevertheless, for the whole Carrara Marble District, the traditional terrestrial photogrammetry can be restrictedly utilised because of the high vertical extension of the excavation fronts. Otherwise, the use of either appropriate mechanical arms or lift equipments cannot be adopted due to their size in respect of the accessibility to the quarries. Such a limitation has been avoided, in this work, by installing the necessary equipment for the photo acquisition on an aerostatic balloon; such a vector must be placed in front of the slope with the possibility of being vertically moved from the working floor to the top of the quarry, in order to obtain the whole photographic cover of the interesting area. The photogrammetric investigation has been used for the analysis of the rockfall events, in order to provide the geometrical parameters necessary to improve the hazard zoning and to plan the right protection measures. The proposed technique in studying rockfall introduced innovative and meaningful characteristics related to the deterministic approaches for the individuation of dangerous elements and the threedimensional analysis of their geometrical relationships with the bounding joints.