Digital 3D Rocks: a collaborative benchmark for learning rocks recognition¹

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Highlights

- A 3D interactive rocks open repository generated using SfM is presented.
- Rocks are organised using a classification system based on their texture.

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- Rocks are classified following a behavioural classification.
- General and specific values of their mechanical properties are provided.
- A description of the rock is provided to aid the naked eye recognition.

1 Introduction

Civil, petroleum, mining and geological engineers, scientists such as geologists, geophysicist and environmentalist, architects and professionals require knowing the main properties of rocks. Although field and laboratory tests provide these properties, in some occasions, it is needed, in terms of economy and time, a faster and prior classification. The sense of sight allows us to learn about the surrounding environment, permitting the assimilation of information from the surroundings, and makes up about 70% of objects perception (Schroeder, 1996). Therefore, the simple naked eye recognition of rocks allows their classification, providing precious information about them. Naked eye recognition of rocks is a mandatory part in civil engineering and architecture professional practice, at least in the preliminary stages of a construction project.

Many authors have published a considerable amount of articles and books on the field of naked eye recognition of rocks (Goodman, 1989; Tarbuck and Lutgens, 2015; The United States. Federal Highway Administration, 1991). Many websites offer the identification, classification and description of rocks (Hudson Institute of Mineralogy, 1993; Imperial College London, 2013; Michna, 1995), being aided by digital pictures or even videos. Those 2D resources cover a wide range such as high-quality photos captured using GigaPan mediums (Benton, 2014). The resources that use videos offer a better

comprehension of the recognition process. However, a major problem is that they cannot exploit the interactive information of hand holding a rock (for example, roughness, the existence of voids or characteristic features). The object motion (rotation and translation) provides valuable information because we perceive most of the features by moving through their three-dimensional structure. Therefore, the use of 3D models makes up a better alternative than 2D static images for the description of a rock. Fortunately, the generation of 3D models is possible thanks to the development of several novel techniques.

Since the early 2000s remote sensing techniques, such as LiDAR (Light Detection and Ranging) or SfM (Structure from Motion), have been applied in many fields to capture 3D scenes. While LiDAR instruments are expensive, SfM technique can be applied using conventional cameras. LiDAR-derived data characteristics depend on, among others, the instrument type, range and environmental conditions. Contrarily, SfM-derived data depend on the software and on used photos, and consequently of the lens, capture strategy, environment and so on. Gigapixel images have also been used for 3D reconstruction (Lato et al., 2012; Lee et al., 2017).

Digital data acquired through remote sensing techniques enables the interactive visualisation of solid surfaces using specific software packages. Therefore, its application to the field of petrology offers a new perspective for naked eye recognition of rocks and improves the study of rocks through the visualisation of their real colours, textures, sizes and shapes (Riquelme et al., 2016). However, this information could be insufficient for the naked eye recognition and classification of rocks. Therefore, a geological description of each rock must be provided along with each digital model.

The present work aims to satisfy two principal objectives: (1) to provide students of engineering, architecture and sciences, who are required to take subjects of geology, with an almost organoleptic 3D system that enables and aids the recognition of the major rock groups; and (2) to provide users a rock classification system that considers their geomechanical behaviour. The authors initially designed this work for students of civil, geological and mining engineering, but it is also useful for other students and professionals thanks to the novelty of the first aim. To satisfy these objectives, we present the full establishment of an open online repository. The open online repository contains 3D digital models and detailed descriptions of the rocks, including their rock classification, texture description, a basic link between their petrological and geomechanical/petrophysical properties, collection place and potential uses in everyday life. The present paper will allow researchers and students to generate their own 3D models along with the proposed data sheet and to upload them to the repository. To encourage users to generate and to upload their models, we describe and detail the full generation process of the 3D models.

It is not the aim of this work to include all rocks, as reference books on petrography mention over one thousand types of rocks (Goodman, 1989), but to upload some main rocks classified in an accepted classification system. Educational framework

Engineering studies must provide solid knowledge to students who will be further employed in the design, building and supervision of different constructions. Students must overcome theoretical concepts and apply these concepts through practice. Traditionally, geology subjects are part of the syllabus of geosciences and engineering degrees. In these subjects, general concepts of geology are provided, and part of the practical study

comprises the application of these contents to the naked eye recognition of rocks and minerals. This process can be performed in the field or in the laboratory where the explanations are supported by physical rocks. However, students rarely have those rocks when studying at home. Using digital models provides complementary information to aid the study process to strengthen skills in rock recognition. This open online repository provides an exceptional framework for students for studying rock collection before, during and after the practical lessons.

Besides geology, rock mechanics is an important part of the syllabus of civil, mining and geological engineers. Rock mechanic subjects aim to analyse the behaviour of rocks and rock masses. Hence, it is a major necessity to understand the rocks through its genesis and its expected behaviour. We propose a simplified description in which students and professionals can find significant values of relevant details, providing an order of magnitude of parameters of those rocks when available.

2 Workflow process of the 3D reconstruction.

The 3D reconstruction of the rocks uses the SfM-MVS technique. The Figure 1 presents the workflow process. In the first stage, the scene is prepared along with metric information. The second stage comprises the photo capture. Finally, the third stage processes the photos and generates the specimen 3D model.

Figure 1. Workflow of the process to generate a full rock.

Figure 2. Preparation of the scene: (a) a flat surface, in this case, a corkboard, is placed on a horizontal surface, targets are fixed to the corkboard and the rock specimen is placed in the centre; (b) several markers are attached to the rock when the rock is captured in various positions.

The first stage comprises the scene preparation. Figure 2 shows an example where a corkboard has been utilised due to its flat non-regular textured surface. Targets were fixed to the surface and the distances between their centres were accurately measured. Second stage comprises the photos capture. In this work, several users reconstruct rocks using their own cameras: Coolpix S2800, Sony DSC W330 (14.1 Mpx) and Nikon D5500, using a fixed lens model Nikkor 50 mm f/1.8G, or domestic smartphone cameras: OnePlus X and Huawei P20 Lite. SfM strategy englobes capturing the specimens by different photos from distinct positions and orientations. The capture of the images must be enough to overlap between neighbouring photos. A good strategy, to guarantee overlap, is to capture photos following an imaginary circumference centred over the rock specimen and pointing the camera to the rock. Figure 3 depicts an example of the described approach where Figure 3 (a) shows the location of the captured photos of a rock specimen.

(a) Capture of photos

(b) Sparse cloud

(c) Dense cloud

(d) Mesh

(e) Textured

(f) Chunk 1

(g) Chunk 2

(h) Aligned chunks

Figure 3. (a) Location and direction (black lines) of the capture of photos (blue rectangles); different processing stages: (b) sparse cloud obtained after alignment; (c) dense cloud obtained after building dense cloud; (d) mesh obtained after building mesh and (e) textured mesh, after building texture; alignment of chunks: (f) chunk 1; (g) chunk 2 and (h) chunks 1 and 2 aligned and merged.

Third stage comprises six steps: (1) alignment of photos; (2) insertion of Ground Control Points (GCP); (3) optimisation of the calibration parameters of the camera; (4) dense cloud reconstruction; (5) mesh reconstruction; and (6) build of textures.

If the specimen is fully modelled, for each position of the specimen the three first steps are applied. Otherwise, these steps are applied only once. First, the alignment process estimates internal and external camera orientation parameters in a local reference system. This process generates a sparse cloud (Figure 3a). Second, metric information is provided to the model which allows conducting a transformation and optimisation process. In this step, the markers are inserted in the scenario and captured along with the rock. Third, camera positions and internal parameters are optimised. When generating a full model, all positions are aligned using the joint markers (Figure 2b) and then merged (Figure 3f-h). Fourthly, the dense cloud is reconstructed (Figure 3c). Fifthly, a mesh is reconstructed to represent the surface of the object (Figure 3d) from the existing dense cloud. Finally, the textures are applied to the previous mesh (Figure 3e).

Different formats are available to export and share results. We used an online platform to share the models.

3 Classification of rocks

The uploaded rocks used a genetic classification into the major rock groups: igneous, sedimentary and metamorphic. In this study, we have considered and adapted the basic rock classification in one of the most common geology reference books (Tarbuck and Lutgens, 2015; Tucker et al., 2009). This classification is based on textural (e.g. size of the grains or foliation) and organoleptic (e.g. mafic rocks are darker than lighter) properties. Although we avoided the use of more specific and complex classifications, such as the proposed by Dunham (1962) for carbonate sedimentary rocks or the International Union of

144 Geological Sciences (IUGS) systematics of igneous rocks (Streckeisen, 1974), we
145 complementarily include and extend the rock description in some complex rocks with the
146 specific classifications. For instance, in the repository, the available sample #7 (Guimaraes
147 granite) is as a porphyritic coarse-grained biotite granite, but it is also termed as
148 monzogranite because of its mineralogical composition IUGS's classification. The repository
149 presents the use classification system ([https://web.ua.es/es/digitalrocks/system-of-](https://web.ua.es/es/digitalrocks/system-of-classification.html)
150 [classification.html](https://web.ua.es/es/digitalrocks/system-of-classification.html)), that defines the organisation of the samples.

151 Igneous rocks are commonly classified by the Streckeisen classification (Le Bas and
152 Streckeisen, 1991; Le Maitre et al., 2002). However, as we focused on rock specimens
153 inspected through 3D models, we used a simple classification based on the rock texture and
154 its composition (Tarbuck and Lutgens, 2015). This classification is not as accurate and robust
155 as the previously suggested but offers an easier way to classify the most common types of
156 rocks to students and non-experts. First, the classification is based on the texture and
157 secondly on the mineral composition and optionally on the rock size, showing the name of
158 the corresponding common rock.

159 Despite the most accepted classification system for sedimentary rocks proposed by
160 Folk (1980), we used a simpler classification (and less robust) (Tarbuck and Lutgens, 2015).
161 The scientific community widely accepts that sedimentary rocks are classified into two
162 groups: (1) detrital and (2) chemical and organic or non-detrital sedimentary rocks.
163 Depending on the texture of metamorphic rocks, the common classification uses two big
164 groups: foliated and non-foliated.

Instead of a genetic point of view, engineers may be more interested in a behavioural classification system such as the one proposed by Goodman (1989), which we applied along with the genetic classification.

4 Information, data portal design and implementation

The repository is defined by two main parts: the database and a website that organises and offers all the virtual contents. The database organisation follows a logical order to classify and describe a rock specimen from the point of view of civil, geological and mining engineers. However, it is noteworthy that users interested in geosciences will also find this work of interest.

To catalogue and describe the specimens, we designed a datasheet which is fulfilled when data are available (Online Resource 1). All rocks must have, at least, two fields: identification number and the name of the rock. Despite the fact that the name of the rock can be identical for several specimens in the database, its number (id) must be unique. All fields are organised in four sections: (1) geological classification; (2) geomechanical classification (behavioural classification according to Goodman (1989)); (3) description of the local sample and (4) engineering classification of intact rocks (general classification according to Deere and Miller (1966)).

The first section classifies the specimen using the genetic classification. This section requires three blocks: introductory definition, petrologist's definition and commercial definition. The first field is the introductory definition, which is a simple definition that enables readers to identify common rocks based upon a visual inspection following a

genetic classification (naked eye). This definition describes the original digitised rock, and it is supported by the digital rock available in the portal. The second field is the petrological definition, which describes the composition and texture of the rock. The last field is the commercial definition if exists. In the second section, the specimen is classified based on the behavioural classification of Goodman (1989). Third section describes the local sample in four fields: (1) local sample description from a geological point of view; (2) additional information about the outcrop; (3) weathering grade of the rock, following the ISRM criterion and (4) location where the rock sample was collected.

All rocks and information are available in the following URL: <https://web.ua.es/digitalrocks>. This portal is organised on a landing page and the rock repository (Figure 4).

In the site, the users can inspect the rock specimens through an embedded visualisation window, provided by the Internet site Sketchfab© (<https://sketchfab.com/>). Besides the online visualisation, the web shows a brief description of the rock and its corresponding geological and geotechnical information. The visualisation of a 3D model allows zooming, translating, rotating and inspecting the specimen's texture in an interactive way. Moreover, the inserted annotations of clasts, minerals, fossils and other features enhance this experience (Figure 4). Details of the texture, grain size and shape, colours, organisation and other geometric properties of the rock surface can be determined by the user. The web also provides a report of the generation of the 3D model. Finally, the data sheet details the collected data of the sample.

Figure 4. Capture of the portal.

5 Conclusions

An open online repository that stores 3D models of rock samples is presented. The main aim of this repository is to be a complementary tool to support the training process on rock recognition, traditionally performed using 2D static images or videos. The specimens are organised following a genetic classification and are presented along with a short description and a datasheet that contains valuable geological and geomechanical information, what will be of interest to geology and rock mechanic professionals. These 3D models provide the opportunity to virtually visualize in three dimensions and in a realistic way rocks specimens as well as to highlight remarkable details of interest for the students as the constituent minerals of the rock and other properties.

At the moment of this work submission, more than 50 common rocks (sedimentary, igneous and metamorphic) were generated using common cameras, and even

smartphones, through the SfM-MVS technique. The methodology to generate scaled rocks is described. This process can be performed by non-experts that will increase their abilities as they practise with the generation of 3D models.

The present work successfully satisfies the following objectives: (1) to provide engineering and geosciences students, who are required to study geology, with an ‘almost organoleptic 3D’ system that enables and aids the rocks recognition and complements the available resources for this process; and (2) to provide users (students and professionals) with a rock classification that considers their geomechanical behaviour. In early stages of this repository, pilot studies were conducted for the students of Geology applied to Civil Engineering in the University of Alicante (Spain). The student’s acceptance and the obtained results demonstrated its potential for geology practices (Riquelme et al., 2016).

It is the purpose of the authors to continue with this line of investigation and to encourage students and professionals to actively collaborate with this repository providing their own 3D models and descriptions of rock specimens from all round the world, offering an accessible reference of 3D geological information.

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