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# DIGITAL MODELS OF STONE SAMPLES FOR DIDACTICAL PURPOSES

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**ABSTRACT:**

This paper presents a virtual methodology based on the generation of virtual models of stones in the context of the virtual laboratories for the acquisition and evaluation of competences in stones identification. The generation of the models is carried out using a procedure based on close-range photogrammetry that allows to obtain a scaled mesh models with radiometric information and low file weight. The proposed methodology has been designed ad-hoc following the economy, quality and reality criteria to ensure a good adequacy, guaranteeing an adequate adaptation to the teaching-learning process and the integration of the models into working packages, which can be easily integrated in earning management system (LMS) platforms. The generated 3D models have a high level of detail and enable the interaction to take measurements, make cross sections and use specific tools that allow the student to perform a thorough analysis and identification of the stone using free/open source software.

## 1. INTRODUCTION

The information and telecommunication technologies and protocols developed during the recent years have had an important impact on the educational paradigm, resulting in substantial improvements in terms of flexibility, interactivity and communication. Furthermore, the application of these technologies implies an improvement in the teaching-learning processes (de Benito, 2008). The paradigm of the European Higher Education area has two critical aspects: the acquisition of competences, and the student-centred teaching (Huber, 2008). Acquisition of competences in visual identification of stones is an important objective of different higher education programs related with architecture, geological sciences and engineering. Identification of stones is normally taught in the laboratories of the universities where a limited number of stones samples are available.

### 1.1. Virtual environments

The virtual laboratories (VLs) have many advantages: on the one hand they allow to reduce the problems related to the excess of students in the laboratories if a large number of students are enrolled or if they are using specific instruments, tools or machines, especially in the cases of highly specialized technological courses (Vergara et al., 2018). Furthermore, in the context of laboratory activities, some specific details about the working methodology, even operations involving the use of specialized equipment cannot be adequately appreciated by the students, even more in the case of overcrowded classrooms.

Therefore, virtual laboratories are postulated as reinforcing and supporting tools that encourage self-learning, and promote participatory environments (Pomares et al., 2017), even improving the motivation (Ayala et al., 2017). Specifically, for university students taking engineering, geological sciences, heritage preservation and architecture programs, the collection of stones (set of stones samples of different typologies) are important training resources in the context of construction materials. Moreover, it is paramount to recognize and identify the different typologies of stones in different technical context as engineering, architecture and heritage documentation and conservation.

The visual identification of the different stones typologies is not a trivial process, since it could be necessary to evaluate different sections of the stones and details and, in this way, rigorously observe their characteristics to differentiate one from the others.

The physical collections of stones have a limited number of samples, are not always available and, sometimes it is difficult to find specific and exotic stones that are complicated to get. For the training in identification of different types of stones, it is necessary to know the geometry, the texture and specific geological details. Furthermore, implementing practical physical activities with collections of stones in physical laboratory contexts could involve the deterioration of the samples, mainly due to the manipulation and possible incidents such as falls or breaks. The limited number of samples is also an important constraint considering that laboratories used to have a high occupation and a high number of students performing observation and active tasks (Vergara et al., 2018). To solve this, a procedure for the three-dimensional

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reconstruction of stones for learning applications and competence acquisition is raised in this manuscript in order to generate virtual models oriented to the learning, e-learning and b-learning activities within virtual environment contexts, which are becoming very relevant and the related works on this issue have been grown since 2005 (Heradio et al., 2016).

In this way, as first step, an adequate protocol to stablish the virtualization requirements for the specific learning / e-learning / b-learning contexts is presented in this paper. This protocol, taking into account the recommendations raised in (Rodríguez-Martín and Rodríguez-Gonzálvez, 2018a; Vergara et al., 2018), will consider three fundamental criteria for the methodological design: reality, economy and quality, which are explained in the next sections.

### 1.2 Virtualization of solids

Different initiatives related to the virtualization of solids for teaching-learning tasks have recently been addressed. In Gutierrez et al. (2018), a procedure for the generation of a virtual collection of woods was proposed. The procedure is based on the texturing of ideal CAD models using textures from high resolution image. In Rodríguez-Martín et al. (2019), virtualization of welds using macro-photogrammetry was proposed for the learning and evaluation task in visual inspection of welds. This activity was well accepted by students in terms of usability, motivation, learning and scalability. Previously, this approach had been proposed using a laser metrological arm (Rodríguez-Martín and Rodríguez-Gonzálvez, 2018b) but radiometric information was not provided directly by the sensor. In the field of the Non-Destructive Testing (NDT) in welding engineering, a virtual laboratory for the application of the ultrasound NDT technique was proposed in Vergara et al. (2018). In Ballu et al. (2016) a virtual laboratory that substitutes an expensive metrology laboratory is proposed, which is based, among others, in models of parts with dimensions, orientation, position and form errors. The visualization of the form error shape could help future professionals to understand potential defects of parts and make optimal decisions.

The previous initiatives in the virtualization of materials demonstrate the good acceptance of the methodologies based on virtual models, especially in those cases where samples of objects must be manipulated in laboratory activities, such as fashion boards, welds or stones, being the latter the object of this paper. The traditional methodological approach to acquire the competences in identification of stones is based on some physical examples of different stones, but normally academic institutions have a limited number of stones samples and, in addition, there are some very particular stones that can be difficult to obtain.

The next sections explain the methodological design based on the virtual models, the generation of the models considering the learning requirements and the resulting final product.

## 2. ACADEMIC CONTEXT

The present virtual materials are not designed for a specific course or degree. Instead, they can be used in a variety of subjects from Engineering to Social Sciences and Humanities. Since the main aim of the 3D models is to help students to acquire competences, Table 1 lists a selection of the most suitable general and transversal competences. Please note that Table 1 does not list any specific competence, since they have to be particularized in the subject.

| Competence | Type |
|---|---|
| ▪ Spatial vision and knowledge of graphic representation techniques by CAD<br>▪ Basic knowledge of geology and terrain morphology and its application in problems related to engineering<br>▪ Analysis and synthesis<br>▪ Use, conservation and maintenance of buildings, writing the necessary technical documents<br>▪ Problem solving<br>▪ Ability to apply knowledge in practice<br>▪ Determine, measure, evaluate and represent the terrain, three-dimensional objects, points and trajectories<br>▪ Ability to intervene in and conserve, restore and rehabilitate the built heritage | Basic |
| ▪ Plan and organize personal work<br>▪ Analysis, criticism, synthesis, evaluation and problem solving<br>▪ Information management | Transversal |

Table 1. Basic and transversal competences related to the proposed approach.

## 3. METHODOLOGICAL DESIGN

The workflow followed for the methodological design which is shown in Figure 1. The sequence followed addresses the complete process of the methodological design of the activity, beginning with a reflection about the real utility of the innovation to be applied and finalizing with the design of evaluation process based on virtual models.

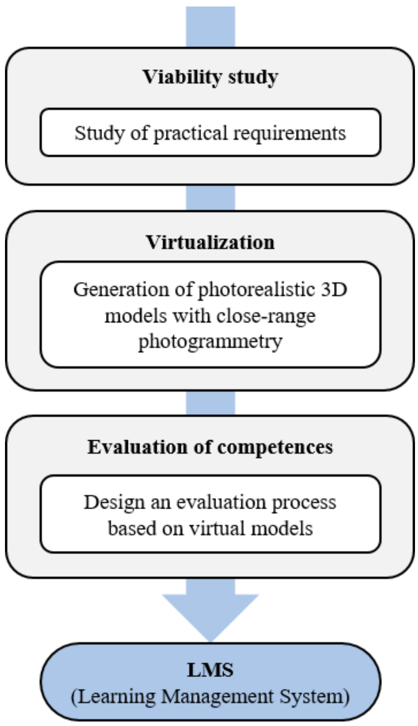


Figure 1. Workflow for the methodological design.

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### 3.1 Viability study

In this phase, the study of the practical specific requirements for the virtualization process is analysed. A deep discussion about the difficulties and problems of the traditional methodology must be considered, as well as the aspects that the new based-on virtual models' methodology can improve with respect to that one. As indicated in the previous section, there are previous works about the virtualization of material with good results. Additionally, the methodology has to be designed based on the important items numbered in Table 2. These items are classified in three global criteria: economy, reality and quality (Vergara et al., 2018; Rodríguez-Martín and Rodríguez-Gonzálvez 2019). The virtualization technology chosen will be addressed under these three criteria.

The proposed methodology for the generation of the virtual models is based on close range photogrammetry. This geomatic technique has been chosen after performing a thorough study of existing techniques for virtualization (structured light, laser scanning, RGB-D sensors, etc.). For this case, it was decided that close-range photogrammetry was the most adequate solution because it allows to obtain an adequate high spatial accuracy and resolution, registering radiometric information. The colour is an important information to distinguish the types of stones, in this way models must have radiometric information. Furthermore, the point clouds generated using photogrammetry can be meshed in order to generate a solid model, on which student can make cuts, sections, thresholds that allow to study the model in more depth. As precedents of the application of the technique, close range photogrammetry has been recently studied for the reconstruction of small sized objects in quality control of welds reaching submillimetre accuracy (Rodríguez-Martín et al., 2016) and it is habitually used in the heritage preservation context (Remondino, 2011).

Although photogrammetry has been used in many research tasks, the works and researches that apply it in competence acquisition within educational contexts are not numerous. The data acquisition using photogrammetry is not as easy as using another technique as laser scanning or structured light. So, in this case, it was considered that the important advantages of photogrammetry justify a more complex data acquisition process due to the potential learning suitability. Moreover, the chosen technology could be considered as a low-cost technique because for the generation of the virtual product, it is only required a Digital Single Lens Reflex (DSLR) digital camera or similar, auxiliary elements and opensource photogrammetric reconstruction software as for example GRAPHOS (González-Aguilera et al., 2018). Within the workflow, a scaling procedure must be also integrated to provide a real metric to the models (active technologies as laser scanning or structured light register the metric directly). For this aim, artificial target and/or scale elements must be included in the scenario during the data acquisition phase to obtain reference points to scale the model within the reconstruction process.

Following the criterion of economy, the versatility of the technique and the possibility of adapting the models for other uses are taken into account. Once the model has been generated, it should be easily distributed, consequently, the computational weight can be optimized to generate lighter models for the easy integration in Learning Manager Systems (LMS) platforms (such as Moodle) or, even, in new platforms oriented to the Cultural Heritage field such as 3DHOP (Potenziani et al., 2015). This aspect will be raised to provide a filtering method to reduce the computational weight of the models, finding, for the proposed objective, an adequate balance between quality and versatility for the simultaneous fulfilment of the economy and reality criteria.

The virtual models generated must be integrated into work packages that also contain the necessary documents for the carried activity and, also, the tutorials for the management of the LMS and the software. These packages must be designed for learning and evaluation purposes.

| Reality criterion | Economic criterion | Quality criterion |
|---|---|---|
| ▪ Radiometric fidelity of the models<br>▪ Adequate geometrical precision and resolution.<br>▪ Possibility to design an adequate evaluation over the models. | ▪ Adaptation of the content files for different academic programmes.<br>▪ Potential for an easy integration in LMS (e.g.: file size). | ▪ Possibility to add additional material to the packages.<br>▪ Possibility to add management and software tutorials.<br>▪ Possibility of competences evaluation.<br>▪ Satisfaction questionnaire. |

Table 2. Criteria for the methodological design

### 3.2. Generation of the virtual models

The first step is the data acquisition that consists on taking photographic images of the entire volume of the stone following a specific protocol and positioning the camera in a convergent trajectory. Firstly, the image set is processed using the aforementioned software, based on SfM approaches, to generate the final point cloud. Initially, an image pre-processing is carried out to aid better feature extraction and matching. In the case of stone sample, this is of interest since there are cases of low texture.

Secondly, the feature extraction and matching using the different detector and descriptor included. Due to the acquisition protocol, the Affine MSD (Tombari and Di Stefano, 2014; González-Aguilera et al., 2018) is the preferred one since it includes the main perspective geometric parameters (camera axis orientation) and it is based on the contextual self-dissimilarity notion, namely, image patches that are highly dissimilar over a relatively large extent of their surroundings hold the property of being repeatable and distinctive.

Next, the self-calibration and bundle adjustment is solved. In this step, external constraints are used to scale the stone model. A set of pre-calibrated artificial targets have been used to this purpose. However, as alternative, a calibrated ruler could be used. Finally, the dense image matching is carried out to generate the final point cloud.

Since the obtained 3D point cloud has not the optimal visualization properties for the learning process (e.g. lack of continuous texture), a meshing operation is applied. As a result, a solid model with high resolution texture is obtained, which can be visualized using free/open applications as for example CloudCompare (CloudCompare, 2019), allowing students the three-dimensional interpretation of the stone and the carrying out of exercises.

One of the constraints related to the teaching using 3D models and the particular need of an e-learning environment is the model's final weight. This is especially significant for mobile learning approaches, where LMS has to ensure that the file size of working package is adequate to be downloaded by a mobile connection (e.g.: 3G) and/or it will take up an inordinate amount of space on a user's device (Nguyen et al., 2015). For this purpose, different filtering methods can be applied to reduce the weight of the mesh models, maintaining at the same time geometric quality (Rodríguez-Gonzálvez et al., 2015). These considerations are also valid in the case of 3D web viewers, where a progressive data transmission is required to improve the data streaming (Torres-Martínez et al., 2016).

### 3.3. Design of the evaluation process

The strategy for the integration of virtual models in a course (using the LMS) has been carried out in accordance with Gutierrez et al. (2018), considering the specific requirements of the presented proposal (Figure 2). In this aim, the course could be structured as follows:

- Teaching guide.
- Evaluation.
- Contents.

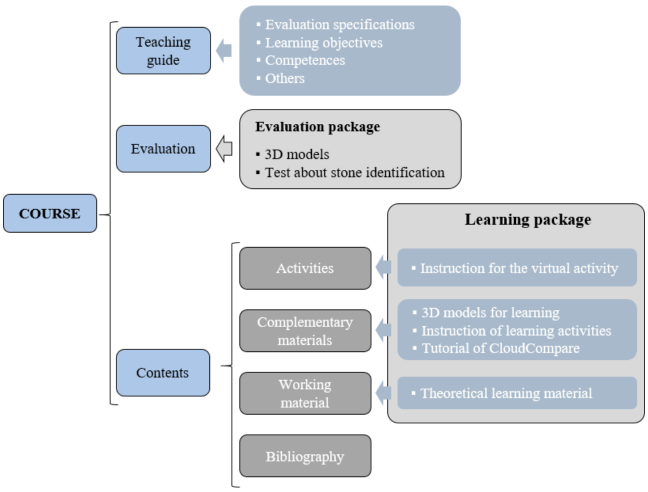


Figure 2. Diagram of the integration of the different activity elements in the LMS.

Next, the course structure is discussed:

1) Teaching guide: it is a document with global information about the course. It can contain the nature and typology of the course, identification of the professors, competences to be acquired by the student, learning objectives, evaluation criteria, etc.
2) Evaluation: in this section, the student must upload the evaluation activities, which should be properly explained in the teaching guide. This package will include the solid models of the stones that the student must identify, as well as tests with questions about the identification of stones. In this way, the student could be automatically evaluated when completing the virtual test because the test could be embedded into the platform for automatic evaluation.
3) Contents: in this section the specific teaching materials of the course will be included. In this manner, complementary material, bibliography, and activities will be given. The working material subsection will provide information about different typologies of stones and the way to identify them. The complementary material subsection will include images with indications for the macroscopic identification of the stones, the virtual 3D models so that the student can manipulate the samples and observe their characteristics virtually. Also, a tutorial that explains all the instruction to use the software CloudCompare is included. Finally, activities subsection includes the statements of activities based on 3D models.

## 4. RESULTS

### 4.1. 3D models

An example of a meshed model of a sandstone with quartzite is shown in Figure 3 from different perspectives. The camera employed was a Sigma DP2 Merrill with an APS-C sensor (24 x 16 mm) and 15 megapixels. The image set was 55 images acquired with an average distance of 60 cm, being the focal length 30 mm. A tripod was used to avoid camera movements due to the long exposure time of approximately 1/10 of second. The internal camera parameters were self-calibrated. The final spatial resolution was approximately 0.1 mm. The scaling was carried out with artificial targets yielding the check points a precision of 0.156 mm. As the reader can see, the solid model generated present a good realism. Many small details of the surface geometry of the rock can be appreciated in the model. Furthermore, the solid model contains colour information, important for the identification of the stone. Additionally, due to the scaling procedure applied, the models have a real metric and students can directly take measures on the model using the measurement tools provided by the software, e.g. CloudCompare (CloudCompare, 2019).

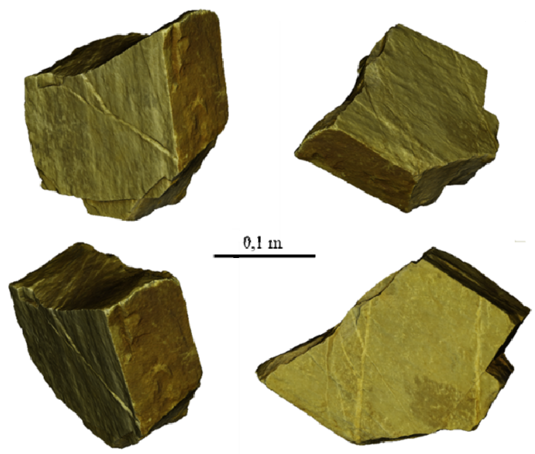


Figure 3. Example of a virtual model of a sandstone. This model has been meshed to generate a solid geometry.

### 4.2. Exercises

Although the complete didactical packages are conditioned by the final subjects where the 3D models will be applied, next a generic set of exercises are shown in order to allow the acquisition of a series of competences and skills:

a) Macroscopic identification of stone components. This is the first and most simple visual identification protocol. It could be described the texture, fabric, colour, brightness, morphology, exfoliation and types of minerals. However, other properties cannot be assessed by the virtual model as density or hardness. In the traditional learning process with physical samples, those are determined by the employment of additional components as a hammer and hydrochloric acid. This competitional skill is acquired by the experience, so the presence of a wide variety of 3D stone models and exotic samples allows the future professionals to improve this skill.

b) Generation of 2D views: A very simple operation, but very powerful to understand the stone sample, and also to carry out classical 2D measurements. The map of the stone's features and also any kind of anomaly allows to improve the students' skills related to conservation and the decision process related to intervention processes. As an example, one specific exercise would be related to the mapping of not only the components, but also deterioration patterns, which are a consequence of the impact of environment factors (Rodrigues, 2015).

c) 3D measurements: Instead of the traditional measurements carried out with calipers (for dimension measures) and tape (for perimeter measure), with the proposed approach a more precise and complete surface stone can be achieved. An application example in Cultural Heritage is the assessment of the weathering process of stones, to prevent structure failure of high valuable historical buildings and monuments (Saba et al., 2018). These dimensional parameters can be also related to other parameters and disciplinary fields, as for example in benthic ecology with the oxygen concentration (Graham et al., 1988).

d) 3D derived parameters: as for example the superficial roughness. Nowadays, this parameter is determined by a comb profilometer. However, the advantages of the 3D models, improve the calculation of this geometrical parameter since it can be determined as the distance between each 3D point and the best fitting plane computed on its nearest neighbours (CloudCompare, 2019). Roughness value can be related to the biological colonization of Cultural Heritage buildings, as well as other parameters as absorption of solar radiation (Kprkanç and Savran, 2015). Subsequently, students will acquire competences related to the maintenance of historical buildings.

### 4.3. Assessment

Along with the didactic packages, internal and external measures will be incorporated. As a result, they will be used for the evaluation of the competence acquisition and their incidence in the improvement of the students' learning by means of the following indicators:

- Survey of student's satisfaction.
- Student's personal comments and conclusions collected in the practical reports. This indicator could be integrated in the teaching guides of the subjects.

## 5. DISCUSSION

Regarding the traditional learning approach based on physical samples, the need to reduce operational and economic problems that occur in laboratory practices motivates the new approach for e-learning. Table 3 summarizes the comparison between both approaches according to the criteria exposed by (Rodríguez-Gonzálvez et al., 2018) and (Rodríguez-Martín and Rodríguez-Gonzálvez, 2019).

Of the parameter exposed, the efficiency criterion includes the difficulty of implementation by the teacher, while the scalability reflects the potential of transfer of the didactic materials to other subjects of the same area of knowledge (Rodríguez-Gonzálvez et al., 2018).

| Parameter | Traditional approach | Virtual model approach |
|---|---|---|
| Activity preparation time | Low | High |
| Activity evaluation time | Medium | Low |
| Activity completion time | Medium | Low |
| Ease to distribute | Very low | High |
| Economic cost | High | Low |
| Efficiency | High | Medium |
| Learning potential | Medium | High |
| Scalability | Low | High |

Table 3. Comparison of the main parameters of the two methodological approaches.

In summary, the use of 3D models and geomatic visualization tools in acquisition and evaluation of competences in stones identification pursues the following results:

- Improve the academic performance of the students, with the acquisition of skills in Information and Communication Technologies, which are transversal skills.
- Evaluate and monitoring learning outcomes, since the didactical packages are complemented by satisfaction surveys and conclusions drawn from the practical reports. The results obtained help to quantify the level of acquisition of the skills by the students.
- Increase student participation and motivation through the use of 3D models and different visualization strategies.
- Develop the autonomous learning capacity of the students since the 3D models could be accessible from the LMS repository. As a result, the student can reinforce the theoretical lessons and/or delve into specific issues.
- The didactic strategy can be transferred to other subjects and degrees, as stated in the scalability criterion.

## 6. CONCLUSION

A virtual collection of stones can be constituted using close range photogrammetry as three-dimensional scanning technology. This technology is the most adequate to obtain models with a high detail level and color registration. The models of the virtual stone generated have a high quality, so they can be used in learning tasks if the methodology is carefully designed following three important criteria (economy, reality and quality).

The technical pipeline proposed allows the systematic reconstruction of meshed models with radiometric information from single RGB images taken around the stone using a DSLR camera. The photogrammetric workflow focuses on the computational weight reduction of the generated point cloud to enable the easy integration of the models into LMS platforms. The application of the technique is direct because new learning and competences evaluation methodologies for learning, e-learning and b-learning can be proposed through the approach based on virtual models that allows to cover the deficiencies of laboratory work, where the number of samples for identification tasks is normally limited, and the number of students is high, causing problems of occupation (Vergara et al., 2018). The three-dimensional generated models are solid, so students can interact with it using a suitable software.

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