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3D Digitization in Architecture Curriculum

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Abstract. *In this paper we describe an experience undertaken in the Faculty of Architecture of Technical University of Lisbon, concerning the introduction of a 3D Digitization course in the frame of the PhD doctorate program in Architecture and in the frame of the Master's programs in Architecture, Urbanism and Design.*

We start by describing the theoretical and instrumental frameworks proposed. Then we describe and discuss a set of two exercises developed during one semester, giving examples of the work produced by the students. Finally we end with some considerations to be taken into account in future editions of the course

Keywords. *3D digitization; architectural recording; laser scanning; digital photogrammetry; teaching and learning.*

INTRODUCTION

In the book *Digital Design Media*, Mitchell and McCullough (1995) describe a design studio fully integrating traditional and digital media. Basically the Building is at the centre and several paths are displayed between the building and its possible forms of representation, being Digital Models one of those forms. According to the presented and well known scheme, the shortest path between the building and the Digital Model is through electronic surveying. This electronic surveying encompasses what can be designated as 3D Digitization.

There are multiple techniques of 3D Digitization, passive and active (Lillesand et al., 2004), range based and image based (Remondino, 2006), using different kinds of light, etc.

This paper describes an experience of implementing a 3D Digitization course in Architecture curriculum.

The goals of this experience were to make architecture students familiar with 3D digitization techniques and tools, to develop their awareness

for the possibility of doing themselves the work, to use freeware and open source software as much as possible in all the workflow from data processing to the final models scaling and orientation, and to propose a theoretical framework for the teaching and learning process of this subject among architecture students.

3D Digitization was offered as an optional course at our University. It could be attended by Architecture, Urbanism and Design master students during their fourth or fifth year of their studies, and by PhD Architecture students during their first year.

This paper is structured in six sections: a) a short history and related work, b) the theoretical framework, c) the instrumental framework, d) the practical exercises proposed, e) Results of the exercises and discussion, and f) conclusions and further work.

A SHORT HISTORY AND RELATED RESEARCH

Traditionally the survey of the built environment

was driven to the production of 2D deliverables. This was particularly true before digital technologies became a common place. The techniques used were the traditional manual and topographic survey, analogic photography and analogic photogrammetry, that relies in the human faculty of perceiving in objects 3D, from pairs of images (anaglyphs), with the aid of some specific instrumental apparatus.

Photogrammetry was then a very expensive and specialized technique, and very time consuming, since all the work was done manually. One of the obvious fields of application was the survey of monuments surfaces.

During the 80ies and 90ies, digital technologies become into broader use. Photogrammetry meets another stage, the analytic, meaning that a computer was used to translate into numerical format the analog inputs of the operator. In this way, although the restitution process was still manual, it became possible to store 3D data in digital format. This was one initial form of 3D digitization as something more direct between the object and its 3D digital model representation. By the same time the topographic survey with electronic distance measurements devices was also in use, but it could only provide a much more discrete digitization that was generally used to set ground control for the photogrammetric survey or for the traditional manual survey (Mikhail et al., 2001).

In the beginning of the nineties optical triangulation scanners time-of-flight laser scanners were introduced. And at the beginning of this century a new kind of scanners, phase-based, much faster, become also into use. Dense point clouds changed the way 3D digitization was done.

Simultaneously, advanced image processing techniques were developed that enabled the use of 2D images to produce 3D dense point cloud models in an almost unattended way.

With the increasing power of computation capabilities, and the sophistication of software, it become more feasible, easier, accessible and cheaper to deal with bigger amounts of data, and in general, to access to 3D digitization. This was also the result

of some kind of merging between the fields of photogrammetry and computer graphics.

In the academic field, in the context of architecture, the insertion of digital technologies opened a Pandora's Box and an endless, and sometimes meaningless, discussion about the harms and benefits of the digital (Mitchell and McCullough, 1995).

Some authors (Duarte, 2007; Duarte et al., 2010) have presented successful experiences about the insertion of digital technologies in the architectural curricula and even mention 3D scanning as part of that insertion (Pupo et al., 2008) in the context of digital fabrication.

On the other hand there is a tradition that follows from the survey field, often linked to architectural heritage documentation or archaeology, that nowadays, fully use 3D digitization techniques, such as terrestrial laser scanning (TLS) or digital photogrammetry (DP). In this context it is common to see courses of Architectural Photogrammetry often supported by Photogrammetry or Survey Labs [1] [2].

We understand 3D digitization as a fusion of these two views, the tradition of survey and photogrammetry and the field of Computer graphics (Remondino, 2006). As being part of a school where we have a diversified range of academic offers, going from Fashion Design and Design to Architecture and Urbanism, we think that 3D digitization techniques can be used with benefit in all these scales, not just in a mere instrumental way, but adding new reflexive possibilities to the praxis. That was the motto for the creation of the 3D Digitization course.

THE THEORETICAL FRAMEWORK

The theoretical framework focuses on acquaintance with the basic knowledge of concepts by the students that allow them to operate in a proper way in an architectural context, mostly from a user standpoint. This is done in a three step approach going from the principles level, to the guidance level and finally to the specification level (Wu and Di, 2009). These three levels work as a metaphor both for the teaching and learning and for the practical framing of the work.

First we start by discussing the 3D digitization techniques and methods in the broader context of recording techniques (Boehler and Heinz, 1999), and these as a tool for the understanding of the built structures (Letellier, 2007). At this level is also important to notice what kind of 3D models can be produced and to understand in what contexts different models are used (Chader, 2008). This is in the principles level.

Then we selected a subset of the 3D digitization techniques as a subject to address in more detail. Namely we selected terrestrial laser scanning (TLS), as an active range based technique, and photogrammetry as a passive image based technique, in particular with the structure-from-motion/multi-view-stereo – SFM/MVS (Snavely, 2008; Furukawa and Ponce, 2009) approach. We discussed the typical workflows and its usual steps and concerns, such as planning data acquisition, data processing, model refinement and model orientation. With respect to model orientation we gave an overview of matrix representation of the transformations of scale, rotation and translation and how to estimate the transformation parameters from homologous sets of data points. This is in the guidance level.

Finally, the specification level corresponded to the statement of terms that students had to follow to accomplish two practical exercises.

THE INSTRUMENTAL FRAMEWORK

The instrumental framework comprises a hardware part and a software part. Both parts are interconnected and influence each other. So, it was necessary to make sure that all students could accomplish their exercises even if some kind of limitation arises.

For the SFM/MVS approach we recommended, but didn't limit to, three operative alternatives: a) My3DScanner [3], b) Photosynth [4] + Photosynth toolkit 11 [5], and c) Visual SFM [6]. The first option implies that all the processing of images is done online, so it suited to students that have severe hardware limitations. The second option allows doing some steps of the processing online whilst other steps are done locally, so it is suited to medium

hardware capabilities. The third option implies that all the processing is done locally what obliges to have better hardware capabilities but also allows a more effective control of the process.

Both for TLS and SFM/MVS point clouds processing, it was recommended MeshLab [7] and CloudCompare [8] as well as Notepad++ [9] and Libre Office Spreadsheet [10] for some manual manipulation of matrices.

For the estimation of transformation parameters, namely for scaling, rotation and translation of the point cloud and mesh models, we recommended JAG3D software [11].

This is a collection of freeware software, some open source, totally available in Internet, what means that all the steps of the workflow, from the point clouds processing from acquisition to the final textured mesh models, can be done at no cost.

This means a bigger democratization of the access to digital recording media. The exception to this rule is the parsing of terrestrial laser scanning point clouds from the proprietary format of the scanner supplier to a more common format such as PTX or PLY, which was done with proprietary software. Since we own a FARO Focus 3D laser scanner, we used Faro Scene to solve for this step.

THE PRACTICAL EXERCISES PROPOSED

Two practical exercises were proposed to the students.

In the first exercise, the students choose an architectural or sculptural detail from which they should be able to produce a textured mesh model, without holes. This was supposed to be done solely from photographic imagery. To scale and orient the produced model, two homologous data sets of points are to be used. One is obtained from the point clouds and the other should be the result of independent measurements done directly in the selected object or scene. In addition to the models, in the end of the exercise, the students should submit a report describing and justifying their options during the work.

In the second exercise, a common set of point

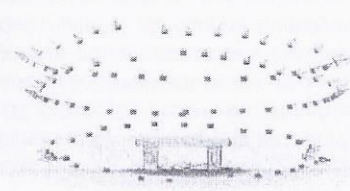
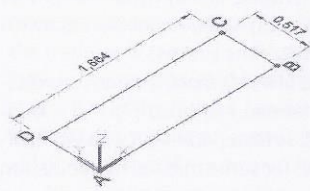


Figure 1
Left: illustration of a reference frame. Center: Cameras relative orientation. Right: Dense point cloud.

clouds, from a terrestrial laser scanning survey of a building, was given to all students. They were asked to follow a described procedure to align the point clouds, to dissipate accumulated errors, and to produce a final merged and sub-sampled point cloud model. This contributed to a broader investigation on the development of an expeditious method for dissipating what we designated as a closure error that arises from the alignment of a closed ring of point clouds.

RESULTS AND DISCUSSION

In this section we describe the workflow that was adopted to do the two aforementioned exercises. While describing the steps of the exercise we will also describe the competences that were supposed to be acquired by the students as well as the difficulties that were felt.

First exercise - 3D digitization small or medium scale object using image based techniques

The objective of the first exercise was to produce a textured mesh model of a small or medium scale object in an architectural context using automatic image based techniques following the structure-from-motion (SFM) principle. First of all it was declared that this kind of techniques have severe limitations in their use to record poor textured surfaces or very reflexive ones, since they rely on the texture of images to recover 3D information. This fact should be understood as constraint about the kind of object that should be chosen; rich texture objects were more adequate.

The statement of the exercise consisted of 10 steps.

- Defining a reference frame in the object. In the simpler form it could be set out as a couple of measurements with a measuring tape in a flat rectangular surface from which one could retrieve the coordinates of at least four control points (CP) as it can be seen in Figure 1 (left and center). Although control points should be widely spread about the object, for the exercise it was allowed to consider them more locally, whilst noting that the first procedure is better since it diminishes the scaling and orientation error.
- Image acquisition. This step involves the understanding of the SFM principle. Images need to be taken with small base distances, what means that the camera view point in space must always be changing and large amount of images with a high level of redundancy is to be taken. It is noticed here that there is no need to use high resolution images. In fact it is better to use more images with less resolution and adopt a hierarchical strategy while taking the pictures. This means that several rings of images at different camera/object distances should be considered. This implies another constraint to have in mind when choosing the object to digitize; the surroundings of the object have to be accessible.
- Image processing is the step where colored dense point clouds are generated. Although this is done automatically we believe that the correct approach is to provide to students

some insight into the phases of this step so this doesn't look like a black box. To understand what happens during this process, even if it is at a superficial level, helps the students to acquire the needed vocabulary to discuss with experts, in the future specialized services are required, and helps bridging the gap with the service providers. This phase includes the following sequence controlled by a set of parameters that determine the quality of the results: a) SIFT, b) image matching, c) cameras relative orientation, and subsequent sparse point cloud generation (Figure 1 right), and d) dense point cloud reconstruction.

- If the outcome of the previous step is more than one point cloud independently placed, then it is necessary to proceed to the relative orientation. Usually, according to the characteristics of the objects and procedures, it is expected that the generated point clouds share the same coordinate frame, that is, the relative orientation comes as a result of the cameras relative orientation. Relative orientation of point clouds will be discussed in more detail in the next exercise.
- Following from the previous step, if one has multiple point clouds, they should be merged to produce a single model. This is important if we want to produce a final "water proof" model that can be used, for example, in digital fabrication. Before merging, spurious data should be removed from the point clouds.
- External orientation is the operation that recovers scale and orientation of the model in the reference coordinate frame. In fact the control points generated in the first step suffice to solve for the seven parameters of the Helmert transformation, that are one scale factor, three rotations and three translations. This is the step where the students with less Math's background feel more uncomfortable. So it is needed to do some extra exercises to explain how homologous data sets can be used to estimate transformation parameters, and to explain the

least squares criterion.

- After the final point cloud is oriented, it follows a decimation operation that results with the purpose to have an even spatial resolution.
- Then a mesh model is created.
- If there are any holes in the mesh they should be filled.
- And finally the color of the points is transferred to the mesh to produce more appealing and realistic models, as it can be seen in Figure 2.

One of the outcomes to achieve with this exercise was to understand that, for many purposes in the architecture framework, one can obtain reliable 3D data without the use of very expensive hardware and without having to hire specialized services. At the same time, by taking into account the restraints that were mentioned, students are capable to understand the potential and limitations of the SFM approach.

Second exercise - relative orientation of terrestrial point

The objective of the second exercise was to orient a given set of 16 terrestrial laser scanning (TLS) point clouds forming a closed loop around an existing building. The point clouds were acquired with a FARO Focus 3D. They were parsed and decimated to 1cm spatial resolution a delivered to the students in the PLY format. This allowed to have smaller files and made the process more feasible. The basic concerns with this exercise were to compare the quality of TLS and SFM/MVS point clouds, to provide a way to evaluate the quality of the orientation process through the analysis of a closure error that arises when one tries to close the loop, and to provide a method for the acceptance and correction of that error by distributing its translation component proportionally to the distances between the origins of the frames of the point clouds.

The statement of the exercise consisted of 5 steps.

- First the point clouds have to be cleaned. Data that presumably didn't remain stationary between scans had to be removed. Otherwise the

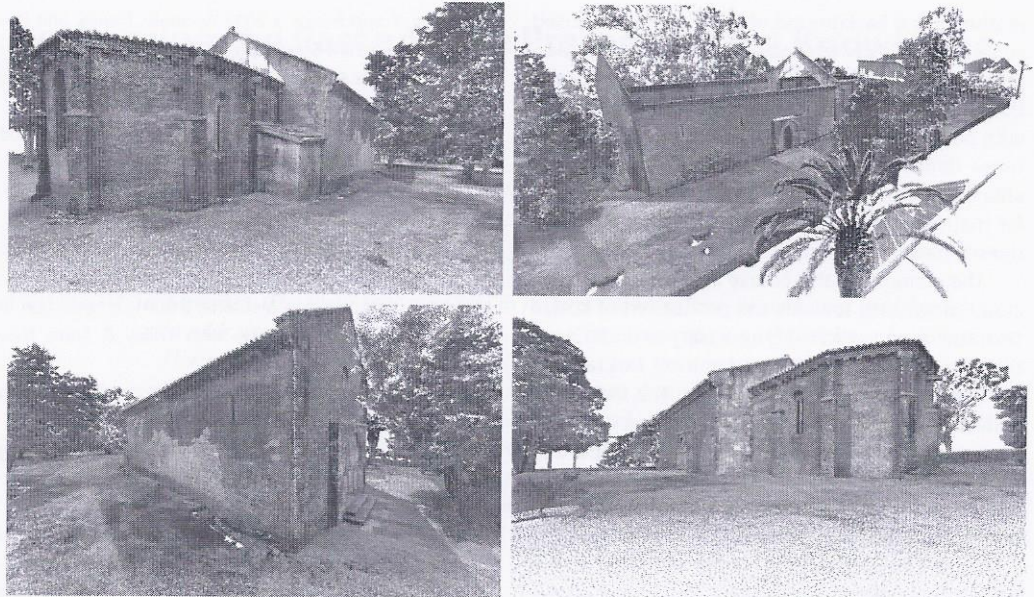


Figure 2
Some of the models that
resulted from the first exercise.

registration (orientation) errors would increase. This task was divided by all the students.

- Then, the set of cleaned point clouds was oriented by a specific order and criteria; each point cloud should only be registered with the previous one and a particular point cloud was set as the reference frame, what means that its position is given by an identity matrix. This way, the final results could be compared. After each registration step, after optimization with the iterative closest point (ICP) algorithm, the student should visually verify if the quality of the registration. This can be easily done by inspecting the point clouds with at least two mobile plans with different orientations and analyzing the section that they produce in the model.
- When closing the loop, that is, when orienting the last point cloud (that is simultaneously the first) with the previous one (the last of the set) its matrix position represents the accumulated error. We refer to this as the closure error as in topography (Casaca et al., 2000).

Figure 3
One of the point cloud models
that resulted from the second
exercise.



- If the closure error is found to be under the acceptable tolerance, then we can consider that no gross errors occurred and we can distribute the error through the poses (matrices) of the point clouds as mentioned above.
- Finally the point clouds were merged and decimated to produce the final model.

In Figure 3 we present an example that resulted from the second exercise.

With this exercise it was possible to verify the need to be careful when dealing with multiple point clouds because if the work is not well controlled, it is easy to accumulate large errors or even to make blunders. Students are then told that there are complementary methods, such as topography, to control the overall quality of the process. But it is also noticed that for medium scale objects, such as the church surveyed, it is possible to use TLS as a stand-alone method. As with SFM/MVS it was also underlined that there are surfaces that aren't good candidates for laser scanning recording. Among those there are glassy surfaces or low reflectance surfaces.

CONCLUSIONS AND FURTHER WORK

The practical results obtained showed that, with a minimum of theoretical framing, satisfactory results can be obtained by agents that are not usually from the field of specialized surveying, and almost with no costs. We notice that, at the PhD level some of the students were architects that didn't even knew about the existence of some of the methods and tools discussed.

It was also interesting to notice that that fact didn't prevent them from accomplishing all the exercises with high quality results. This means a shift in the paradigm for architectural recording and means bridging a gap between fields of knowledge that traditionally were separated. At the end, it was achieved the idea that new possibilities arise by adding these methods and tools to the architect toolbox. It was possible to understand that the techniques presented can be used alone or together or complemented with other techniques, such as topography or manual survey.

We also noticed that, in some cases, the lack of

mathematical background of some students caused some difficulties when dealing with matrix notation and when operating with geometrical transformations via matrices. The issue was easily overcome with complementary materials and exercises where those difficulties were addressed. This is unavoidable since there are some degrees that don't offer mathematics on their curricula and the course doesn't have any prerequisites.

The contents of this course focused in the point cloud processing towards the production of scaled textured mesh models. It is necessary to understand that, usually, this is not an end in itself, but rather a starting point for further modeling. The discussion with the students at the end of the semester pointed out they felt to have acquired a very important tools for the future, but they also noted that it would be interesting to give a further step in the application of the produced models.

As a consequence, in future editions of this course, broader concerns will be considered, namely, practical uses of these models and how to use them as positional, geometric and radiometric constraints for the production of other kinds of 3D models such as Nurbs models or CAD/BIM models.

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