Published as: VANDENBULCKE, A., DE RYCK, M., STAL, C., GOOSSENS, R., DE WULF, A. (2015). Applied surveying education: documenting cultural heritage in 3D in the city of Ghent (Belgium) using laser scanning and photo modelling. Paper presented at the FIG WORKING WEEK 2015 "From the Wisdom of the Ages to the Challenges of the Modern World", Sofia (Bulgaria), 17–21 May 2015, 10 pp.

Applied surveying education: documenting cultural heritage in 3D in the city of Ghent (Belgium) using laser scanning and photo modelling

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Key words: Surveying engineering, photo modelling, laser scanning, cultural heritage

SUMMARY

For several years the city of Ghent (Belgium) and the Ghent University, Department of Geography have been working together to document and measure important cultural heritage sites in 3D. The partnership enables master students in Geomatics and Surveying at the Ghent University to take part in a project driven measuring campaign. During the project, students use and compare several 3D data acquisition methods. This allows the students to implement their theoretical knowledge in the field. The used methods are analysed and critically compared by the students. Through this hands-on-training, students are encouraged to think "outside the box". When problems occur, they are stimulated to think how these problems could have happened and most importantly how they can solve them. The documentation of these historic monuments in Ghent will be used during future renovation works and archaeological research. This paper will discuss the measurements in the Ghent City Museum (*Stadsmuseum or* STAM).

The following methods are applied during the extensive field work: engineering surveying using total station and GNSS, photo modelling and laser scanning. The deliverables are created in a CAD or GIS environment. After successful completion of the course, students have gained a significant expertise concerning the processing of topographic data, 3D point clouds and imagery in an integrated way. This knowledge can be used after their studies to assess which equipment is most suitable for any given survey project. The final products of the photo modelling and the laser scanning process is a 3D model. Furthermore, digital elevation models and orthorectified images of the historic monument can be created. The orthorectified images are visualised and processed into high resolution orthophoto plans, in a CAD or GIS environment.

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1. INTRODUCTION

The documentation, registration and visualisation of a cultural heritage site in 3D is performed using various data acquisition techniques and methods. For several years the city of Ghent (Belgium) and the Ghent University, Department of Geography, have been working together to document several of the city's many important heritage sites. Each year, a group of master students in Geomatics and Surveying, work together to document a particular site. During the project, students learn the advantages and disadvantages of different acquisition techniques and they compare the precision of each method. For this project, they use, analyse and compare the following techniques to register the objects: engineering surveying using total station and GNSS, photo modelling and terrestrial laser scanning.

For the last 4 years, the chosen heritage site was the Ghent City Museum (*Stadsmuseum* or STAM). The STAM is located at the historic Bijloke site, a former hospital site dating from the seventh century AD and onwards. The museum itself is housed in the fourteenth century Bijloke Abbey, in the adjoining seventeenth century monastery buildings and in a recently constructed extension with modern architecture (STAM Gent, 2015). The walls of the facades are restored in an intense red color and the white plaster around the windows contrasts sharply with this red color. Around the courtyard of pleasure garden, roses and shrubs are symmetrically located (Laleman, 2014, Figure 1).

Figure 1: Ghent city museum (http://www.visitgent.be/)

2. DIFFERENT TECHNIQUES

2.1 Engineering surveying using total station and GNSS

The project starts with the measurement of several Ground Control Points (GCP). These GCPs will be used to georeference all measurements in the Belgian Lambert72 coordinate system (EPSG 31370). The points are measured using a Trimble R8 Global Navigation Satellite System (GNSS) receiver. To achieve a high accuracy in the range of 1 to 2 cm, the measurements are based on a Real Time Kinematic (RTK) network solution of the Flemish Positioning Service (FLEPOS, AGIV, 2014).

A second set of GCPs consists of highly distinguishable features on the walls around the courtyard, like corners of stones, edges around windows or details of ornaments. These points were topographically measured using a reflectorless total station Trimble M3. On each wall, a minimum of 40 GCPs are unambiguously defined. These points will be used to compare both techniques with each other during the statistical analysis and not for the georeferencing during the photo modelling process or the registration of the laser scanning point clouds. Hence, it is important to consider these GCPs to be independent. A third set of measured points are the targets used during the measurements with the laser scanner.

The GNSS-based GCPs allow to perform an absolute orientation in post processing, so that the resulting point clouds, digital elevation models and orthophotos are georeferenced in the Belgian Lambert 72 coordinate system (Nuttens, 2009). Since all data sets are referenced using the same primary GCPs, absolute spatial coherence is gained, and relative comparison of the results allows to define a cross-wise quality evaluation.

2.2 Photo modelling

To make a 3D model and orthophotos of the wall of the museum using photo modelling, digital photographs were recorded. These photographs were taken with an 11 megapixel Canon EOS 1Ds camera. This is a full-frame (24 mm x 36 mm) digital autofocus single-lens reflex. A 50 mm lens was used, aiming at a photo scale of the approximately 1/500. A cloudy day was selected to avoid sunlight and harsh shadows.

The images are processed using a Structure from Motion and Multiview Stereo (SfM-MVS) workflow, as implemented in Agisoft Photoscan Profeccional. SfM-MVS enables the construction of 3D models based on a large series of images. SfM-MVS is a technique to reconstruct the camera acquisition parameters and to calculate a sparse point set of the scene (SfM). This step involves the detection of feasture points in each image and the matching of these points with corresponding points in consequtive images. Moreover, it is a technique to acquire the 3D geometry of an object, or a series of objects (MVS), using a series of 2D images. The acquired geometry is triangulated and a texture map is projected on the resulting mesh, allowing an accurate and photorealistic representation of the modelled object (Stal, 2012). During the 3D reconstruction, various GCPs are assigned to the virtual reconstruction. This allows the construction of orthophotos, DEMs and fully 3D models in an absolute coordinate system. An example of the resulting 3D model is presented in Figure 2.

Figure 2: Visualising the orthofoto's of the façades of the Ghent city museum

2.3 Measurements with terrestrial laser scanning

The next method students have to master, is terrestrial laser scanning. All walls are scanned using laser technology. The advantage of laser scanning is the recording of huge numbers of points with high accuracy in a short period of time (Verhelst, 2008). Students work with a Leica phase-based laser scanner HDS6100. The horizontal and vertical angle increment of the resolution level was 0.018°, which results in a point spacing of 7.9 mm at a distance of 25 meter. A laser scanner is a line-of-sight device, so to achieve a complete coverage of the site, different scanning positions are necessary. During the post-processing, the individual point clouds have to be registered together. To do so, the students use a target-to-target registration, using black and white targets, for which at least 3 targets in the overlapping are of the scans are used. These have to be spread over the site and placed on different heights for the best accuracy. To georeferenced the resulting point cloud in the Belgian Lambert72 coordinate system, the coordinates of the center of the targets are measured with a total station, together with a set of reference points.

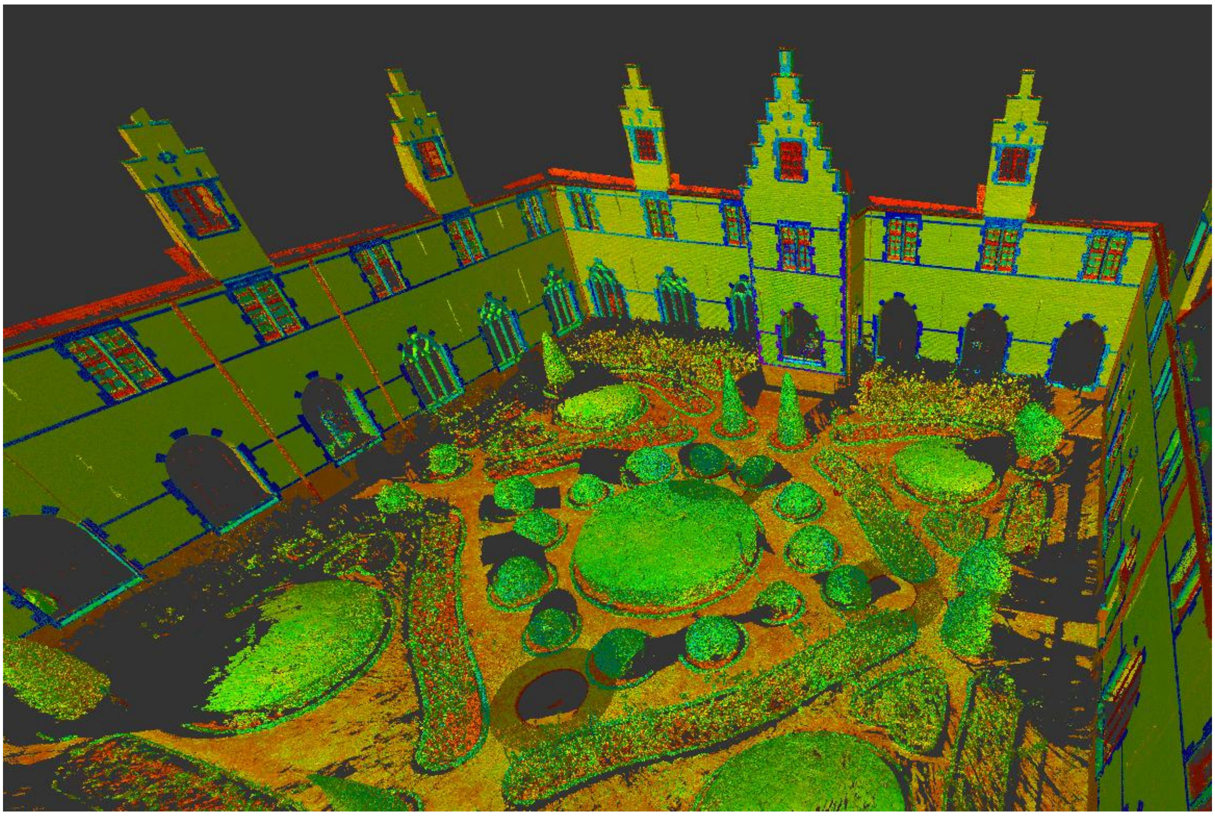

Figure 3: Intensity colored point cloud of Ghent city museum using laser scanning (own research, 2015)

3. ANALYSIS

Students compare thoroughly the techniques of photo modelling and laser scanning using the topographical measurements of the set of characteristic points. The coordinates in this point set are considered as the 'true' values. These values function as a set of independent control points. The coordinates of this set of selected control points are determined in the model created with photo modeling and in the laser scan point cloud. With the use of statistical analysis the differences (in x, y and z) are analyzed. For each point the difference is calculated.

A first comparison concerns the Root Mean Square Error (RMSE). This value is used to indicate how large the error is between two data sets (in this case the topographical coordinates and those obtained through photo modelling or laser scanning).
When comparing the total station values with the photo modelling (after elimination of outliers) the RMS-errors in x, y and z amount to 4.1 mm, 8.2 mm and 6.9 mm. The comparison between the total station values and the laser scanning values, after elimination of outliers, results in RMS-errors in x, y and z of 4.2 mm, 4.1 mm and 4.2 mm (see figure 4).

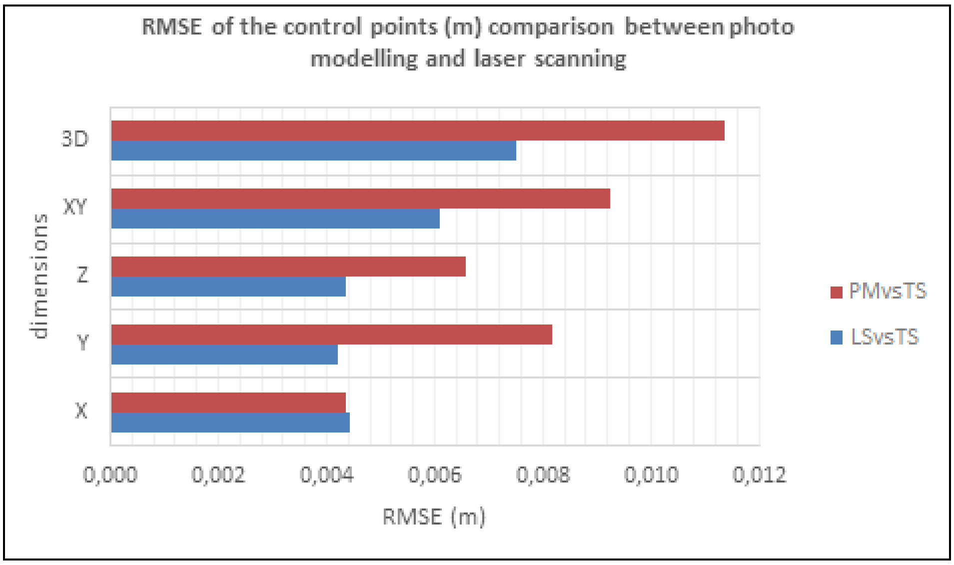

Figure 4: Root mean square error of control points (m)

A second comparison is performed on the systematic error of the control points. Systematic errors are the result of the methods and systems that are associated with the acquisition technique. When comparing the total station values with the photo modelling (after elimination of outliers) the systematic errors in x, y and z amount to -1.7 mm, -4.0 mm and -1.8 mm. The comparison between the total station values and the laser scanning, after elimination of outliers, the systematic errors in x, y and z are 0.8 mm, -2.0 mm and 0.2 mm (see figure 5).

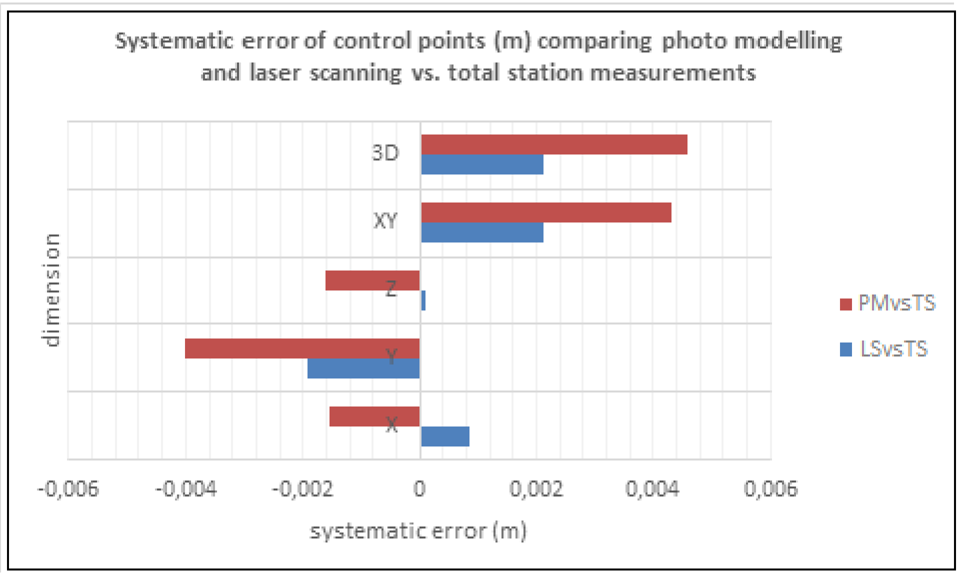

Figure 5: Systematic error of control points (m)

Students are also stimulated to compare their results with each other group. To do this they use the open source software Cloud Compare to visually compare the point clouds received from photo modelling and laser scanning. As an example, in figure 6, the result shows that the laser scan point cloud of one group lies in front of the laser scan point cloud of another group. De scalar value is set from -1 cm till 1 cm. The red pixels are the positive values: points from group 1 lay before the points of group 2. The blue pixels are point behind the point cloud. The histogram shows that there's a systematic deviation of circa 5 mm between both point-clouds.

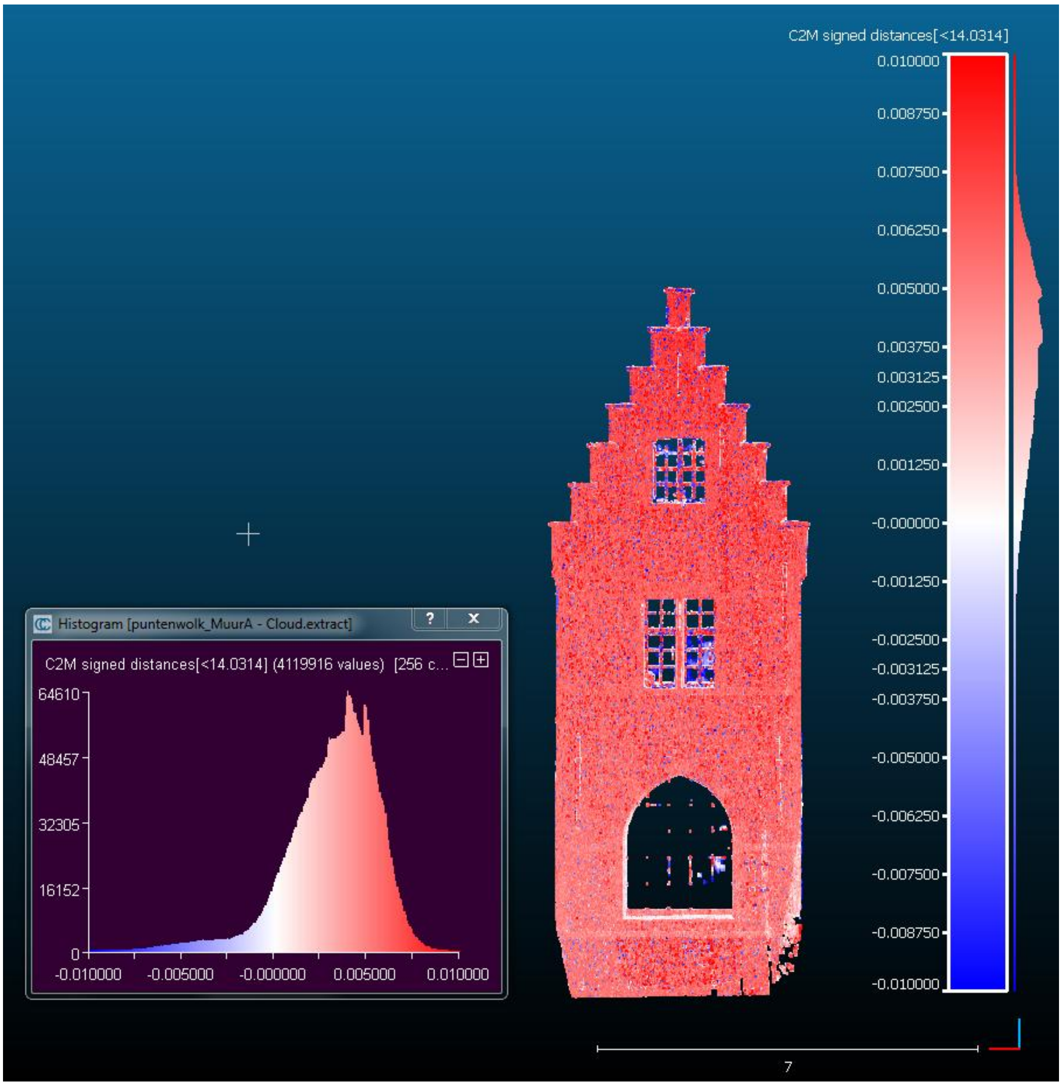

Figure 61: Difference model of the laser scan point cloud between 2 groups using Cloud Compare

4. RESULTS

The final products of the photo modelling and the laser scanning process are a 3D point cloud. Furthermore, digital elevation models and orthorectified images of the historic monument are created. The orthorectified images are visualised and processed, in a CAD or GIS environment, into high resolution orthophoto plans. The resulting plans undergo a profound quality assessment before being delivered to the city of Ghent. The documentation of this historic monument in Ghent can be used for many purposes, such as historical digital preservation and conservation, cross-comparisons, monitoring of shape and colours, simulation of aging and deterioration, virtual reality/computer graphics applications, 3D repositories and catalogues, web-based geographic systems, computer-aided restoration, multimedia museum exhibitions, visualization,… (Remondino, 2011).

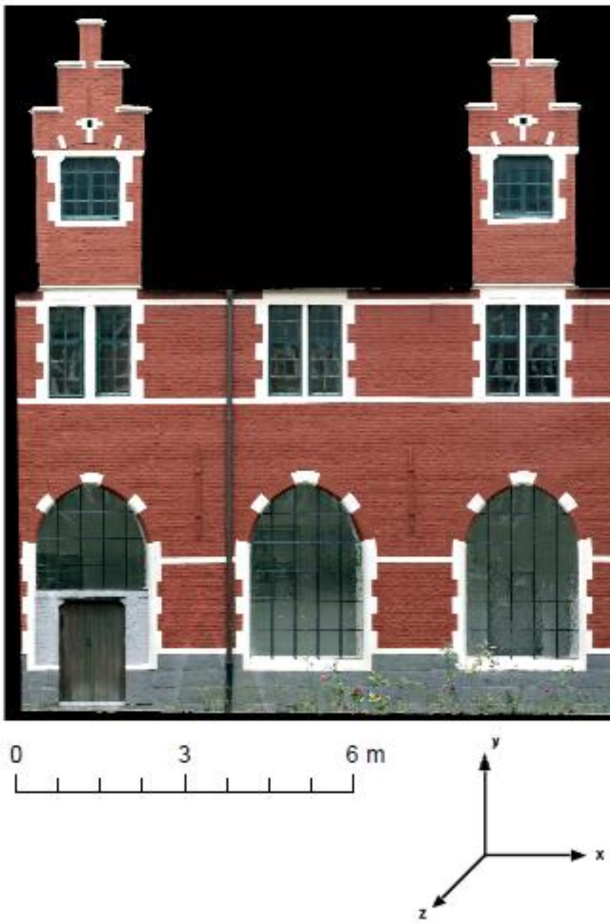

Figure 6: Example of a high resolution orthorectified plan

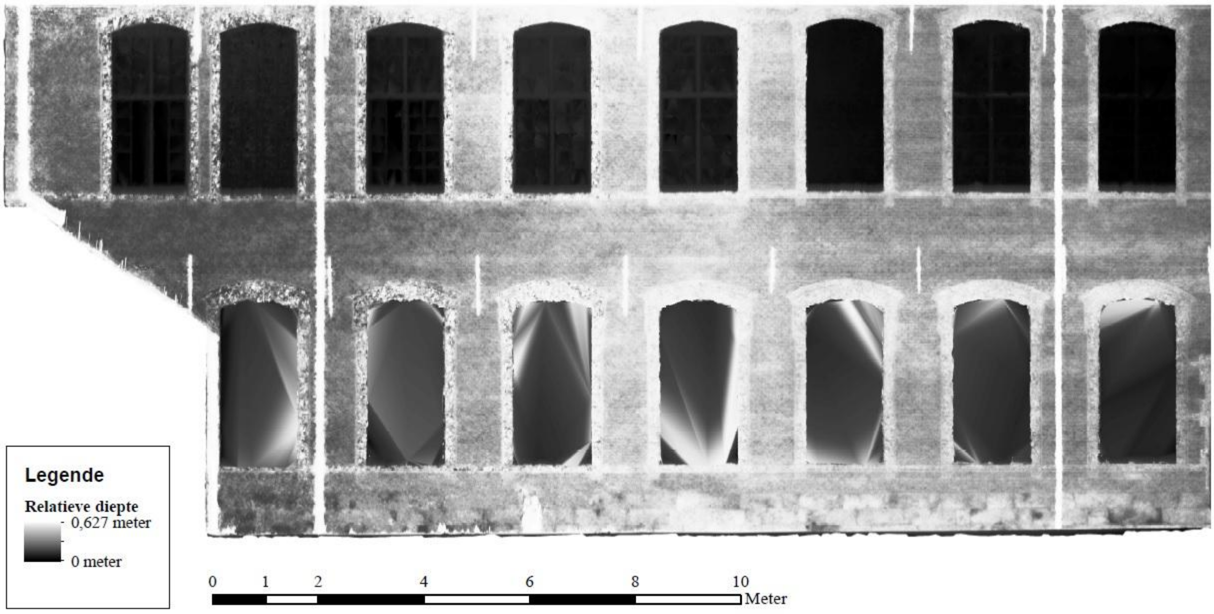

Figure 7: Example of a created digital elevation model

5. CONCLUSION

During this project, students use and compare several 3D data acquisition methods. This way, the students implement their theoretical knowledge in the field. A thorough understanding of the usage of the survey equipment and the importance of correct post-processing is an essential part of their education. By working on an important cultural heritage site, they are stimulated by the fact that the work they are doing is useful for historical heritage conservation.

The students also experience the challenges of working together on a real-world project. Through this hands-on training students are encouraged to think outside-the-box. When problems occur, they are stimulated to think how these problems could have happened and most importantly how they can solve them. When the project is finished, students have gained a lot of extra knowledge concerning the processing of point clouds, the Structure From Motion process and the 3D modelling process in general. This knowledge can be applied after their studies to assess which equipment and methods are most suitable for any given survey project.

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BIOGRAPHICAL NOTES

Annelies Vandenbulcke is an academic assistant and PhD-student at the department of Geography at Ghent University (Belgium). As an academic assistant she supervises several courses during which students acquire practical training on the general principles of 3D data-acquisition techniques. Within the framework of her PhD she researches to optimize the integration of a laser scanner, a Geographic Navigation Satellite System (GNSS) and an inertial navigation system (INS), to be used for hydrographic applications.

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