Training in Mapping Changes on an Archaeological Site

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Key words: innovative learning, 3D modelling, laser scanner

SUMMARY

The evolution of technologies makes surveying accessible to a broader community of professionals and students. Therefore, teaching geomatics is a continuous challenge. This article presents an original pedagogical approach based on a teaching unit gathering students in architecture, as well as in civil and environmental engineering. Working together to collect and visualize data from the built and natural environment is a very stimulating experience. However it requires multiple competences in data analysis and mapping. At the Ecole Polytechnique Fédérale de Lausanne (EPFL), the Faculté de l'Environnement Naturel, Architectural et Construit (ENAC) has introduced a teaching concept called “Projeter ensemble” which consists in a series of multidisciplinary courses. This paper presents a teaching unit for mapping changes of the natural and built environment, focusing on a project carried out in the antique theatre of Aventicum (now Avenches), which is one of the major Roman settlements in Switzerland. The teaching activity has been proposed for 4 years. During this period, restoration works of the antique theatre have taken place and the archaeological site has been surveyed regularly. Hence it is an excellent opportunity to analyse the evolution of the theatre through the comparison of 3D surface models from different epochs.

The students benefit from an exciting field of experiment. They collect real data and build 3D models, which they analyse with adequate software. In this sense, they develop very good skills in data processing and in quality assessment of the mapping products. This teaching unit does not aim at training a few specialists in geomatics. However it contributes towards the critical use of modern mapping tools in widespread domains of activities.

RESUME

L'évolution des technologies met la mesure de terrain à portée d'une plus grande communauté de professionnels et d'étudiants. Dans ce contexte, enseigner la géomatique est un défi permanent. Cet article présente une approche pédagogique originale réunissant des étudiants en architecture, en génie civil et en ingénierie de l'environnement. Travailler ensemble pour collecter et visualiser les données de l'environnement naturel et construit est une expérience très stimulante. Toutefois elle requiert de multiples compétences en analyse et représentation des données. A l'Ecole Polytechnique Fédérale de Lausanne (EPFL), la faculté de l'Environnement Naturel, Architectural et Construit (ENAC) a introduit un concept pédagogique appelé "Projeter ensemble" qui consiste en une série de cours interdisciplinaires. Cet article présente une unité d'enseignement de la cartographie des changements de l'environnement naturel et construit, focalisée sur un projet réalisé dans le théâtre antique d'Aventicum (aujourd'hui Avenches), qui est l'une des principales localités romaines de Suisse. Cette activité pédagogique est proposée depuis 4 ans. Pendant cette période, des

travaux de restauration du théâtre antique ont eu lieu et le site archéologique a été régulièrement cartographié. C'est donc une excellente occasion d'analyser l'évolution du théâtre en comparant des modèles de surfaces 3D d'époques différentes.
Les étudiants bénéficient d'un champ d'expérimentation passionnant. Ils collectent des données réelles et construisent des modèles 3D qu'ils analysent à l'aide de logiciels adéquats. En ce sens, ils développent de très bonnes compétences en informatique et en évaluation de la qualité des produits cartographiques. Cette unité d'enseignement ne vise pas à former quelques spécialistes en géomatique. Cependant, elle contribue à l'utilisation critique d'outils cartographiques modernes dans des domaines d'activités très variés.

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1. INTRODUCTION

The school ENAC (Architecture, Civil and Environmental Engineering) of the Ecole Polytechnique Fédérale de Lausanne (EPFL) has introduced a teaching concept called "Projeter ensemble" which consists in a series of multidisciplinary courses on environmental, construction, urban and land management. The pedagogical approach proposed in these courses is mainly based on practical experiments led by teachers from different disciplines for a group of students in architecture and engineering. Within this interdisciplinary context, this paper will present an innovative way to teach the analysis and the quantification of the changes of natural and built environments, by the means of advanced technologies for surveying and mapping.

Architects and engineers are working and planning at different scales of the territory, which requires good skills in combining different sources of information for the design and the visualisation of projects. The proposed teaching unit is covering different sizes of objects from an isolated piece of construction to a part of a territory and this paper will present the mapping of an archaeological site.

2. TEACHING UNIT

The school ENAC is proposing undergraduate programs (BSc and MSc) and postgraduate programs (PhD, Master of Advanced Studies) with most of the fundamental disciplines of civil and environmental engineering, as well as architecture, and also a series of advanced courses. The disciplines of geomatics are included in the curriculum of engineering and the basics of surveying and mapping are introduced during the first year with a massive online course called "Eléments de géomatique" (Gilliéron, 2015).

Teaching and learning together is a key element of the pedagogical approach proposed by ENAC with an active promotion of interdisciplinary courses shared by lecturers from different horizons. In the framework of "Projeter ensemble" and in cooperation with architects, civil engineers and geomatics teachers, we have introduced a teaching unit developed for the acquisition and visualisation of the natural and built environment.

The teaching unit consists in a half-day per week during a full semester when students from the three sections can work and learn together on a specific topic proposed by a group of teachers[1]. In this context the main topic of this teaching unit is the measurement and quantification of changes at different scales. A particular focus is given to the use of geomatics technologies, like laser scanning, for mapping the changes at different scales (deformation of a beam, archaeological inventory and land cover evolution).

[1] https://enac.epfl.ch/projeter-ensemble/unites-enseignements-enac

2.1 Pedagogical concept

This teaching unit is proposed during the third year of the bachelor. At this level of the studies students already acquired good skills in basic sciences, fundamentals of geomatics, design and structural engineering. They have also some practical exercises in the field or workshops, mainly with a strong focus on a specific discipline. Therefore, they have few opportunities to work together on multidisciplinary topics. A teaching unit is composed of a series of lectures from instructors in architecture, civil and environmental engineering, which bring a common knowledge to the students. The number of contact hours of lectures is limited, because the main part of the learning process is dedicated to hands-on work or the study of use cases where the students are working in small groups combining architects and engineers.

The teaching unit in geomatics technologies for the measurements of changes is composed of three parts; firstly the acquisition and visualisation of a single construction, secondly the deformation measurements of a structure and thirdly the mapping of changes of an urban or natural area. For each subject the groups of students are asked to design the experiment, to collect data on site, to measure with surveying instruments and to process data with specific software. Once they have gathered the appropriate field data, they are able to proceed to some analysis and to create maps or 3D models. At each step of the processing chain a particular care is taken to assess the data quality and to control its consistency. To detect errors or misleading information, the teachers introduce the principle of data redundancy. This point is crucial while combining multiple data sources at different scales (Merminod, 2013).

2.2 Mapping of changes

The deformation measurements or the monitoring of landscape have a long tradition, which is based on the monitoring of specific points with different surveying techniques (theodolites, total stations, and photogrammetry). This approach requires a good a priori knowledge of the site or object to be monitored. One needs to mark and to maintain the network of points. This task is costly and requires a lot of fieldwork, especially to monitor natural hazards like landslides. Such a model based on discrete points has the advantage to provide accurate measurements of displacements between epochs for these isolated spots. However, there are large gaps between the individual points. This is not an issue if the density of points is consistent, but can be critical in case of heterogeneous zones. Thus the use of terrestrial or aerial laser scanner capturing the whole area with millions of points has completely changed the paradigm of the geo-monitoring (Barras et al, 2013).

2.3 Data collection based on point cloud

Figure 1 shows the scan of the Bessières Bridge and illustrates the complexity of scanning big objects in an urban environment. Many terrestrial scans are needed to construct a complete 3D scene. Furthermore manual processing steps are necessary to filter out useless points.

Figure 1: 3D scan of the Bessières Bridge in Lausanne *(Archeotech)*

Compared with traditional surveying techniques like total stations, laser scanners show high potential for deformation monitoring, thanks to the fast data capture, as well as the 3D visualisation. The high-density datasets of the monitored object provide a chance to extract distinctive deformation of different parts of this object. However, this induces new challenges to manage large datasets, outlier filtering, hole filling, and 3D object reconstruction (Jing et al, 2012).

Figure 2 illustrates the possibility to extract elements of the bridge from the orthoimage and to produce a scaled elevation drawing. Students have performed the data acquisition and the drawing during the teaching unit in 2013.

Figure 2: Orthoimage (top) and drawing (bottom) of the Bessières Bridge in Lausanne
(Archeotech, students ENAC-EPFL)

High performance computers and specialised software enable the processing and management of millions of points. Creating orthoimages from 3D point clouds is an efficient way to reduce the amount of raw data for extracting and drawing some specific features of the scene.

3. SURVEYING OF ARCHAEOLOGICAL SITE

In 2014 the practical experiment of the teaching unit was the geodata acquisition of an antique theatre located in Avenches (CH), which is one of the major places of the Roman period in the West part of Switzerland (de Pury-Gysel A., 2011). This site has been surveyed by the students with different acquisition techniques: terrestrial laser scanner, drone equipped with digital camera and total stations, with the expertise of Archeotech, as well as the support of both the Museum of Avenches (see acknowledgment) and the association Pro Aventico. The 3D model of the Theatre (~120 m × 80 m) is composed of millions of points and high quality orthoimages, which have been used for the analysis and visualisation of the archaeological site (Figure 3).

Figure 3: Orthoimage drapped on the DTM of Avenches *(Archeotech, EPFL)*

3.1 Data acquisition

The data acquisition of an archaeological site is a real challenge because each zone has its own importance and built objects have irregular shapes, unlike modern constructions. Both scales are important: the overview of the site and the location of each stone. For this reason we have combined different technologies for the acquisition of data: a drone with a digital camera to produce orthophotos, a terrestrial laser scanner to acquire 3D point clouds, as well as total stations and survey grade GPS receivers to determine reference points accurately.

The recent development of unmanned aerial vehicles (UAV) equipped with digital cameras and positioning sensors makes photogrammetry a great option to model small built or natural areas (Rehak et al, 2014). This technology was fully appropriate to fly over Avenches and to take digital images of the whole area (Figure 3). Images with a higher resolution were captured over the antique theatre (Figure 4 right). The orthophotos have been processed from massive bundles of raw images, as well as a digital terrain model (DTM).

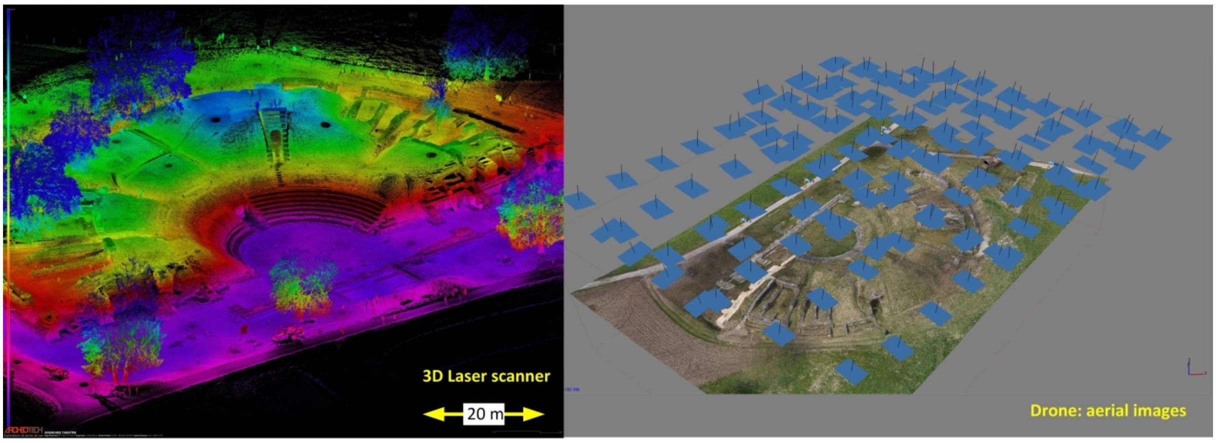

Figure 4: 3D laser point cloud (left) and aerial images (right) *(Archeotech, EPFL)*

The terrestrial laser scanner was installed on twenty stations (Figure 5) to acquire point clouds comprising millions of points. All scans have been assembled in a coherent and unique coordinate system, which is compatible with the Swiss grid (Figure 4, left). Getting access to such a 3D model with dense points is very useful to process orthoimages, as well as to generate horizontally or vertically scaled drawings.

Figure 5: Students learning about laserscanning

3.2 3D Modeling

Using laser scanners for the acquisition is very fast. However, a great number of points are useless and some parts of the object are visible from very few stations. The filtering and manual editing of the points is tedious, but necessary to produce raw point clouds like on Figure 4 (left), which reflects a large number of useless points (e.g. vegetation, people).

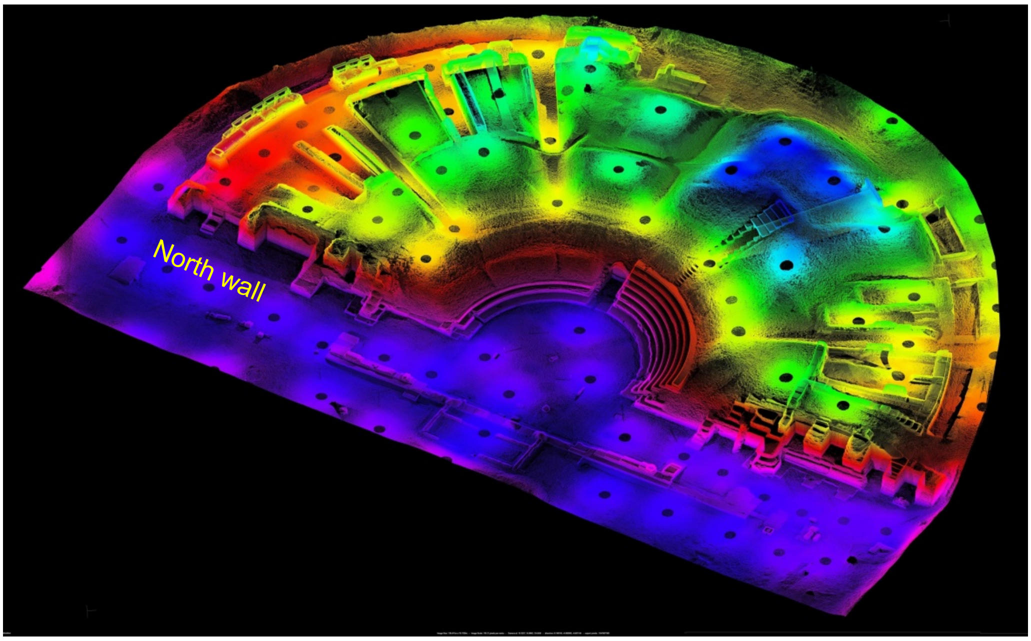

Figure 6: Cleaned 3D point cloud, epoch 2010 *(Archeotech, EPFL)*

Removing all the undesired points is mainly a manual and time consuming process, but it is a crucial step to generate a data set adequate to represent the surface of the object (Figure 6). After filtering, we were able to create a 3D mesh (Figure 7, left), from which precise geometrical information is extracted to visualise the scene. Additive manufacturing, also referred to as 3D printing, is appropriate to create models out of polymer. Figure 7 (right) shows the one generated at EPFL using the mesh of the antique theatre.

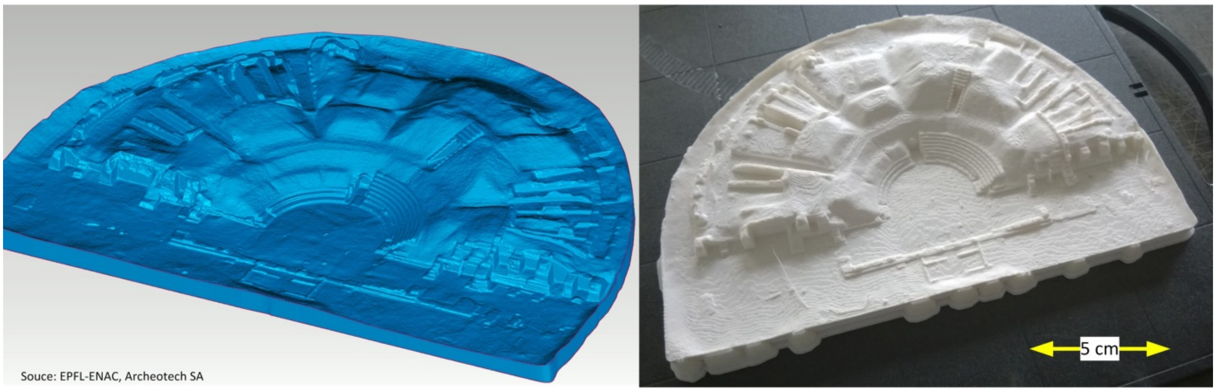

Figure 7: 3D mesh (left) and 3D print (right) of the theatre, epoch 2010 *(EPFL)*

4. MAPPING OF CHANGES

The archaeological site of Avenches is regularly surveyed and a restoration program of the antique theatre has started in 2012 (Aventicum, 2014). The main goal was to reinforce the masonry in order to improve the stability of the walls. As the site has been surveyed in 2011, it was possible to compare the evolution of the theatre with the new set of data acquired from 2014 to 2017. The quantification of changes is based on the comparison of point clouds from different epochs. Using the open source software "CloudCompare" the students were able to monitor the changes and to visualise the differences between mesh models[2].

4.1 Monitoring of the restoration

Figure 8: Restoration of the masonry of the north wall (orthoimages)

The reference model of the antique theatre has been measured in 2010 before the beginning of the restoration work. The example presented on Figure 8 is the north wall of the theatre with the reconstruction of the main piece of masonry (in light brown). The location of the wall is shown on the left side of Figure 6.

In 2016 we have operated a new survey of the area with a drone equipped with a high-resolution camera. All digital images were processed to create a dense point cloud. Although this model is generated from vertical pictures, we used it to represent the 2016 epoch. The accuracy of the new point cloud is good enough to monitor the main changes due to the restoration work.

Figure 9 (top) shows the combination of both point clouds in order to visualize the effect of the restoration, which is highlighted in brown. The bottom of Figure 9 is the result of the point cloud comparison from both epochs. The new masonry is highly visible with large height differences of several decimetres.

[2] http://www.danielgm.net/cc/

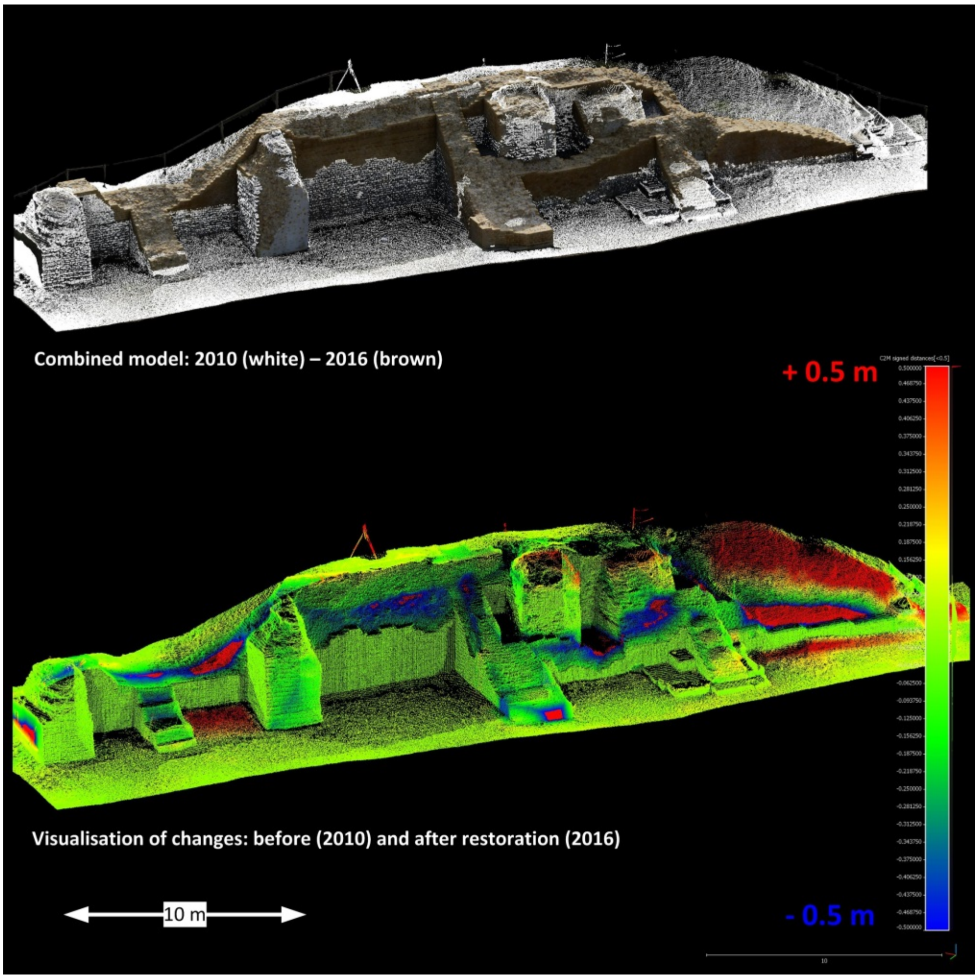

Figure 9: Comparison before and after restoration of the north wall
(dark red or blue means "big change", e.g. reconstruction)

4.2 Effect of erosion

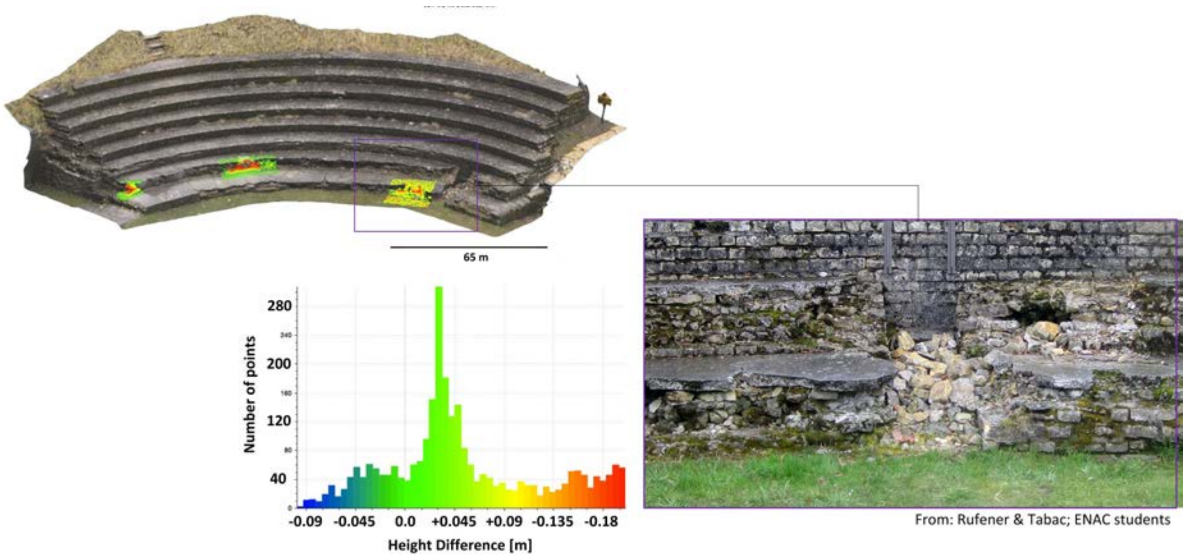

Figure 10: Evaluation of the erosion phenomena

In the early 20th century, mortar was laid to protect the central area of the antique theatre, and Figure 10 illustrates its degradation. We can visualise the height differences between 2010 and 2014 on the shape of the steps. The histogram shows the numbers of points with a difference larger than 10 cm in orange and red, which reflects the erosion effect mainly due to the weather conditions (rain, frost).

5. CONCLUSION AND PERSPECTIVES

The students largely appreciate this teaching approach, even though the goal is not to learn deeply the surveying and mapping techniques. During a semester they have the opportunity to handle real data and to access an exciting use case with the antique theatre of Avenches. This old construction seems to be simple to model, but there is no regular shape. At each step the students have to think about the best way to compare epochs and to extract relevant information. Playing with such a data set is stimulating ideas within the team of students and teachers who are continuously sharing their own expertise in surveying, mapping and 3D modelling.

After 4 years of monitoring an old stone site we have selected a very different type of construction: “Le Polydôme” (Figure 11) on the EPFL campus. The surveying approach is quite similar, but not the goal of the experiment. This time, we ask the students to understand how the construction was designed, built and upgraded. Originally a wooden structure, external coating and internal insulation were added later to improve the comfort.

Figure 11: Panorama of the indoor environment of the Polydôme.

The basic 3D models (indoor and outdoor) and the orthoimages are useful for the interpretation of the role of the different pieces of wood. This 3D data acquisition is mainly based on terrestrial laser scanner, drone-based photogrammetry and 3D/360° digital camera. This exercise is an excellent opportunity for the students to become familiar with building information models (BIM). Involving database concepts as well as practical know-how, teaching BIM is a real challenge. Starting with the capture of the basic building model and then moving towards more complexity by adding new objects into the model is a natural way to progress in this new domain.

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BIOGRAPHICAL NOTES

Pierre-Yves Gilliéron is research and teaching associate at EPFL. He leads several projects in satellite navigation, mobile mapping and road traffic. His teaching activity covers fundamentals of geomatics, satellite positioning and intelligent transportation systems.

Jérôme Zufferey is architect, computer scientist and lecturer at EPFL. He is teaching basics in CAD for architects (Bachelor) and he is coordinating the teaching unit entitled “Mapping of changes”. He is in charge of the IT resources for the Architecture Section of ENAC.

Bertrand Merminod is professor at EPFL and head of the geodetic engineering lab. He teaches estimation methods and geomonitoring. For some years, his research team has concentrated on navigation and remote sensing using unmanned aircrafts.

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