Teaching Unit in Geotechnologies for Mapping Changes of the Built and Natural Environment

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Abstract. Teaching geomatics is a continuous challenge with the evolution of technologies which enables more and more accurate measurement and modelling of the environment. This paper will present an original pedagogical approach based on a teaching unit gathering students in architecture, civil an environmental engineering. Working together in collecting and visualizing data from the built and natural environment with advanced tools like laser scanners is a very stimulating approach that requires multiple competences in mapping and data analysis. A number of practical examples (bridge maintenance, archaeological site, city management) are presented from the field operations to the 3D visualisation and mapping. Each of these topics is illustrated with comparison maps.

Keywords: Laser scanner, Point cloud, Geomonitoring, Digital Elevation Model

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 geotechnologies 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.

Geomatics engineering is broadly used in many disciplines and the recent advances in technology provide more and more tools and valuable geoproducts which need specific knowledge to be used. For this reason EPFL is strongly engaged in the education of geomatics in different sections (architecture, engineering) and has developed e-learning tools for improving the capacity of teaching to a larger number of students. A first step of e-learning in topography was developed by the Geodetic Engineering laboratory (TOPO) with the web-based tools called "Exomatic" (Deshogues, 2010).

More recently the EPFL is promoting the development of Massive Open Online Courses (MOOCS) for disseminating fundamental knowledge to world-wide students with a particular focus on engineering, basic sciences and informatics disciplines. The TOPO lab took the opportunity in 2013 to develop the first French MOOC in geomatics which is now available on the platform Coursera (http://moocs.epfl.ch/). This twelve weeks (eight lessons) MOOC gives an overview of the fundamentals in geomatics with a particular focus on the data acquisition (total station, GPS) and data mapping and visualisation[1].

2. Multidisciplinary 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 and architecture, and also a series of advanced courses at the master and PhD levels. 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 built and natural environment.

[1] https://www.coursera.org/course/geomatique

The concept of a teaching unit consists of a weekly half-day during a full semester (14 weeks) where students from the three sections can work and learn together on a specific topic proposed by a group a teachers.

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 geotechnologies, like laser scanning, for mapping the changes at different scales (deformation of a beam, archaeological inventory, and land cover evolution).

2.1. Pedagogical Approach

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 practical experiments or the study of use cases where the students are working in small groups combining architects and engineers.

The teaching unit in geotechnologies 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 in 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. When they have gathered the appropriate information according the goal of the experiment, they are able to proceed to some analysis and to create maps or 3D models. At each step of the processing chain a particular attention is put on the assessment of the data quality and the control of data consistency. The principle of data redundancy is introduced by the teachers in order to detect errors or misleading information. This point is crucial while combining multiple data sources at different scales (Merminod, 2013).

2.2. Geotechnologies for 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 field work, especially for the monitoring of natural hazards, like landslides. Such a model is based on discrete points and has the advantage to provide accurate measurements of displacements between epochs for these isolated spots. However, there is a lack of information in the areas between individual points, which is not an issue if the density of points is consistent, but which can be critical in case of heterogeneous zones. Thus the use of terrestrial or aerial laser scanner that captures the whole area with millions of points has completely changed the paradigm of the geo-monitoring (Barras et al, 2013).

The example of Figure 1 presents an erosion map which has been generated by the comparison of two sets of laser point clouds measured at different epochs. The impact of the erosion process due to a water fall is clearly identified and precisely quantified (vertical changes from 0.022 m to 0.105 m).

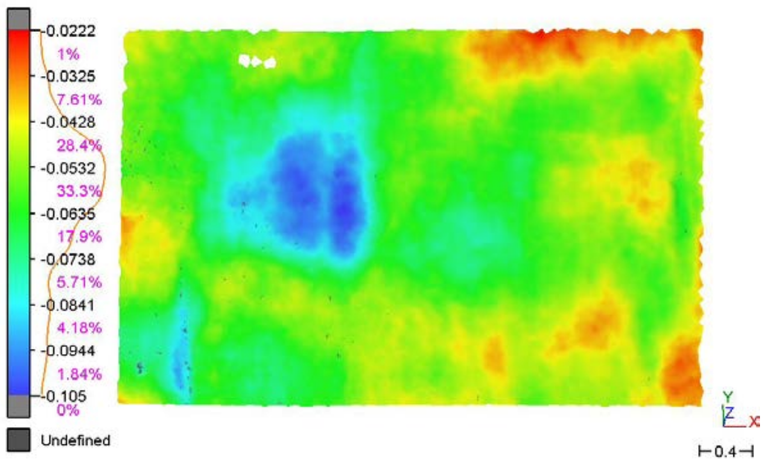

Figure 1. Erosion map of an area in a concrete slope (Units in meter) (HEIG-VD, Barras V).

The example shown in Figure 2 with the scan of the Bessières Bridge illustrates the complexity of scanning big objects in an urban environment. Many terrestrial scans needs to be gathered for the construction of a complete 3D scene of the object and the filtering of useless points requires high manual work and processing.

Figure 2. 3D scan of the Bessières Bridge in Lausanne (Archeotech).

Compared to traditional surveying techniques like total stations, laser scanners show high potential for deformation monitoring, thanks to fast data capture, high data density, and 3D visualisation. The high-density datasets of the monitored object captured by laser scanners 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 3 illustrates the possibility of extracting elements of the bridge from the orthoimage and producing a scaled elevation drawing. The data acquisition and the drawing have been performed by students during the teaching unit in 2013.

Figure 3. Orthoimage (top) and drawing (bottom) of the Bessières Bridge in Lausanne (Archeotech, students ENAC-EPFL).

The processing and management of millions of points is possible with specialised software and requires high performance computers. Creating orthoimages from a 3D point clouds is an efficient way to reduce the amount of data for extracting and drawing some specific features of the scene.

The following sections will present in detail two examples of practical exercises realised by the students during the teaching unit. The first example (section 3) is the acquisition and mapping of a Roman Theatre whereas the second example (section 4) is focusing on the analysis of the evolution of land cover in Geneva.

3. Mapping 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 and the support of the Museum of Avenches (see acknowledgment), and the association Pro Aventico. The 3D model of the Theatre (~120 m x 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.

3.1. Data Acquisition with Scanner Laser and Drone

The data acquisition of an archaeological site is a real challenge because each part of the construction has its own importance and no built objects have regular shapes like modern constructions. Both scales are important: the overview of the site and the detail and location of each stone. For this reason we have combined different geotechnologies for the acquisition of data: a drone with a digital camera for the production of orthophotos, a terrestrial laser scanner for the acquisition of 3D point clouds, and total stations and GPS receivers for the surveying of accurate reference points.

The recent development of unmanned aerial vehicles (UAV) equipped with a digital cameras and positioning sensors, makes the use of photogrammetry more accessible for capturing images on small built or natural areas (Rehak et al, 2014). This technology was fully appropriate for flying over Avenches and taking digital images of the whole area (Figure 4) and more precisely of the antique theatre, which has been captured with higher resolution images (Figure 5 right). The orthophotos have been processed on the basis of multiple raw images, massive bundles of images, orientation parameters and a digital terrain model (DTM).

Figure 4. Orthoimage drapped on the DTM of Avenches (Archeotech, EPFL).

The acquisition of point clouds has been performed with a terrestrial laser scanner which has collected millions of points from twenty stations. All scans have been assembled in a coherent and unique coordinate system which is compatible with the Swiss coordinate systems (Figure 5, left). Getting access to such a 3D model with high density of points is very useful for the processing of orthoimages and horizontal or vertical scaled drawings.

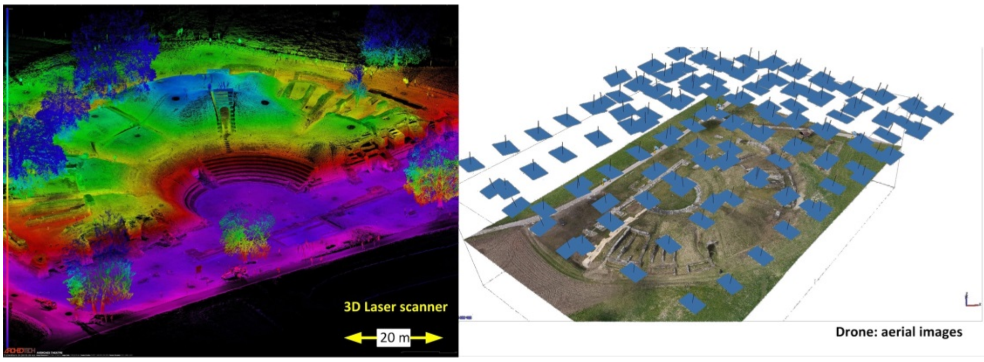

Figure 5. Theatre and its surrounding: raw point clouds (left), 3D view of aerial images captured by drone (right) (Archeotech, EPFL).

3.2. 3D Modelling and Visualisation

Using laser scanners for the acquisition is very fast. However, a great number of points are not useful and some parts of the object are not visible from the stations. The filtering and manual editing of points require a lot of effort for the production of usable models, like the raw point clouds on Figure 5 (left) which reflects a large number of useless points (e.g. vegetation, people).

After filtering, we were able to create a 3D mesh (Figure 6, left) which is a continuous 3D surface that can be used for extracting precise geometrical information or for the visualisation of the scene.The advanced technology of printing is appropriate for creating automatically 3D models made of polymer. The 3D printing shown on Figure 6 (right) has been created at EPFL with the mesh model of the antique theatre.

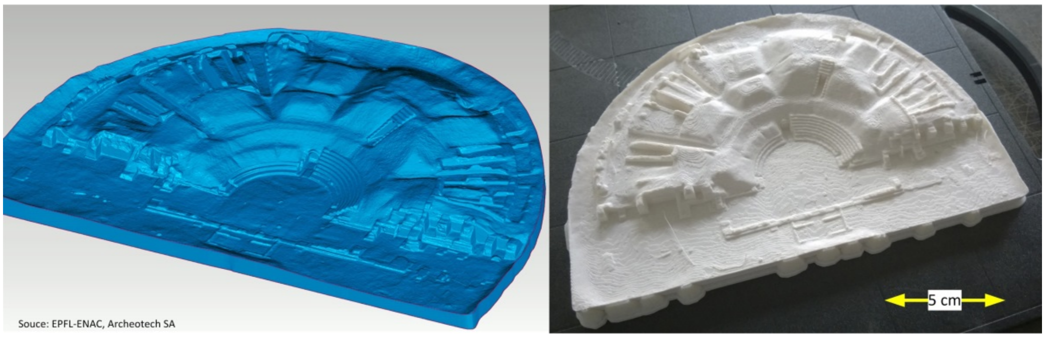

Figure 6. 3D mesh (left) and 3D printing (right) of the theatre (EPFL).

Another option for the production of maps from point clouds is the generation of vertical or horizontal profiles, which is the classical approach used by architects and engineers for the interpretation of terrain or built objects (Figure 7).

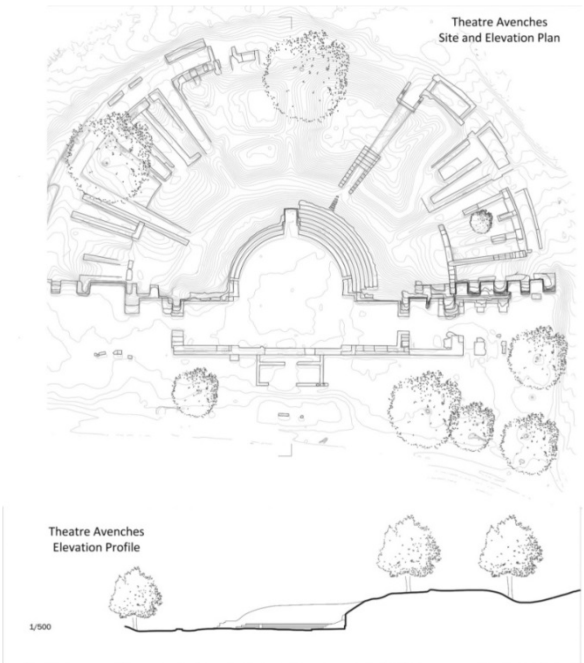

Figure 7. Elevation map and vertical profile (EPFL, students ENAC)

3.3. Evolution of the Antique Theater

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 the consolidation of the masonry in order to improve the static of 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 in 2014.

Both Digital Elevation Models (DEM) have been combined and a map of changes (Figure 8) illustrates the difference in height between 2011 and 2014. The locations B and C show the interventions due to the work of restoration with differences larger than 0.1 m. Apart from the area A (trees), minor changes are also visible on the rest of the zone, which reflect the presence of vegetation or an erosion process.

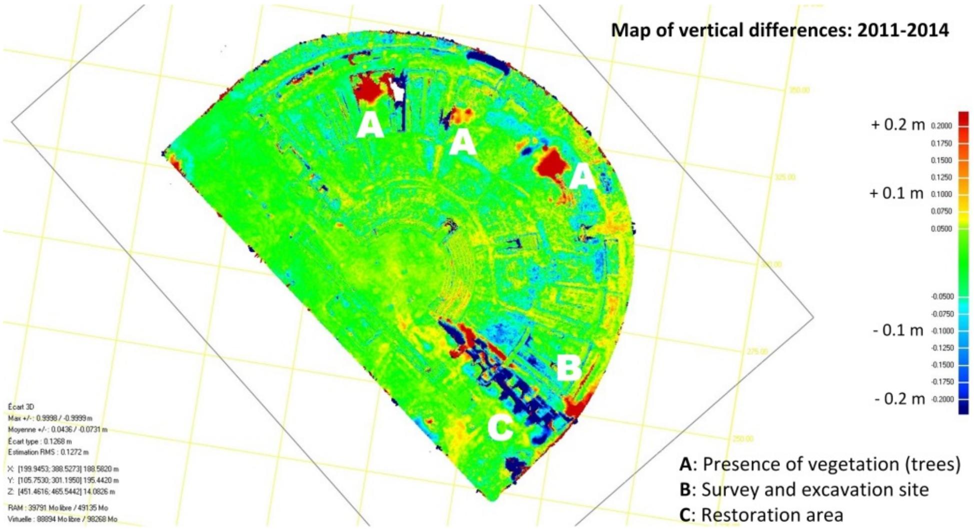

Figure 8. Map of vertical differences between 2011 and 2014 (Archeotech).

4. Mapping of Changes in Urban Environment

Urban and natural environments are continuously changing and the interval between map updates needs to be reduced because many applications (road and city management, assessment of natural resources,...) depend on basic geodata of high quality. In this context the use of new geotechnologies, especially for data acquisition and mapping, plays a key role in the process of database maintenance and in the provision of efficient geo-services.

This section will present a methodology for the assessment and mapping of all changes, mainly the evolution of the built environment that can happen in a city. Using point clouds at different epochs allows to process automatically datasets for the creation of maps illustrating the evolution of an urban area. This method has been used in a neighborhood area of the *Canton de Genève* where high resolution DEM are available at different epochs. Several maps and 3D models have been generated with points cloud analysis software.

4.1. Comparison of Aerial Point Clouds

Aerial laser scanning is an efficient method for the acquisition of digital elevation models which can represent the surface of the terrain (DTM) and the digital height model (DHM, cover elevation model), including all natural (forest) and built objects (houses, road infrastructure).

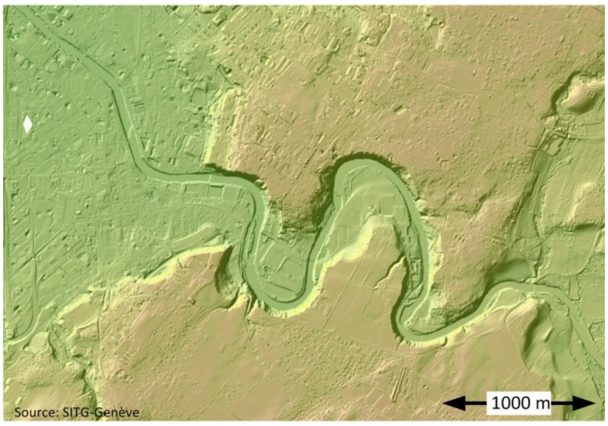

Figure 9. Digital terrain model (DTM) (source: SITG, Genève).

The *Canton de Genève* with its *service de l'information du territoire*[2] (SITG) is a provider of geodata and point clouds based DEM. The EFPL students had access to datasets for their exercises in the analysis of point clouds and identification of changes. For this purpose they used DTM (see Figure 9) and DHM from epochs 2005, 2009 and 2013. The procedure of comparison consists in the processing of height differences between DHM from two epochs.

[2] http://ge.ch/geoportail/pro/

The data processing is performed with a point cloud software that has the capability of combining datasets from different epochs. The open source software CloudCompare[3] is an efficient tool for the production of maps of changes. Therefore, the point clouds must be *a priori* classified in order to compare objects of the same class (e.g. buildings, vegetation).

The SITG is providing DHM datasets with identified points resulting from the classification process. They will be used for the point clouds comparison of specific data types between epochs. In order to assess correctly the model accuracy, it is important to compare elevation models of the same type. Figure 10 shows the possibility of comparisons between point clouds and between triangulated irregular networks (TIN).

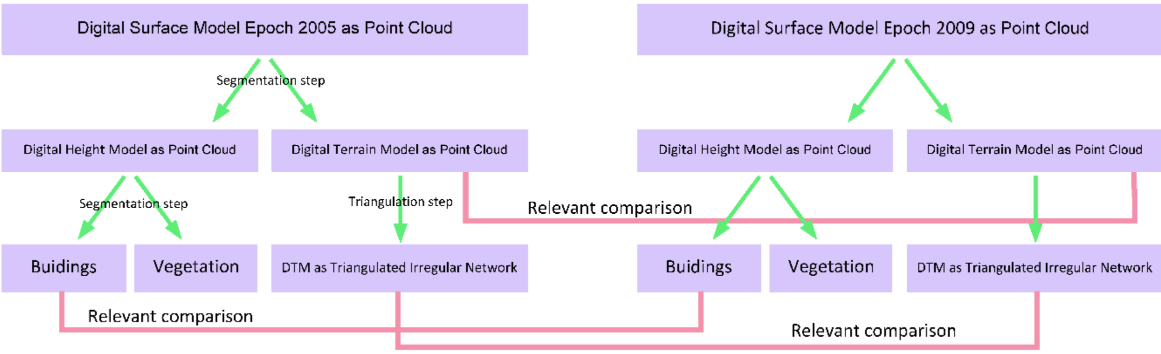

Figure 10. Dataflow for the comparison of DSM, DHM and DTM.

4.2. Quantification and Visualisation of Changes

The identification of changes has been performed on an urban area of Geneva where several modifications of constructions were effected during the last decade. Figure 11 shows an urban area with the identification of buildings and vegetation (in black). The visual comparison between the epoch 2005 and the epoch 2013 presents the evolution of relevant objects (red circles).

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

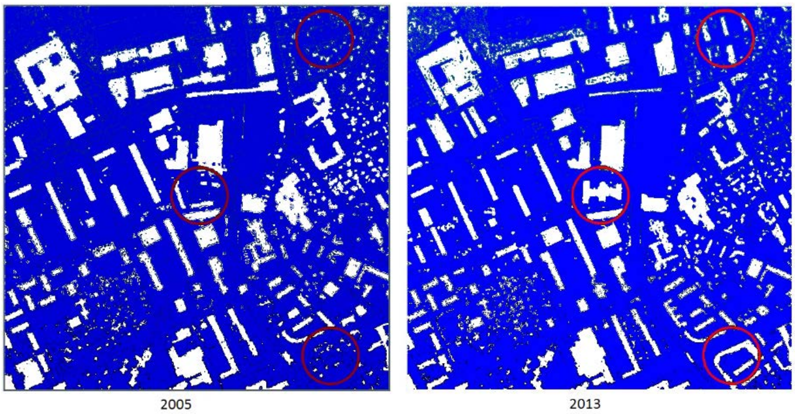

Figure 11. Map of changes, city of Geneva.

Figure 12 illustrates the detection of new constructions based on the comparison of DHM between two epochs. The aerial orthophotos show also this evolution, which is clearly evident in this case. Nevertheless this detection technique can be applied to any type of surace for detecting changes on built and natural objects.

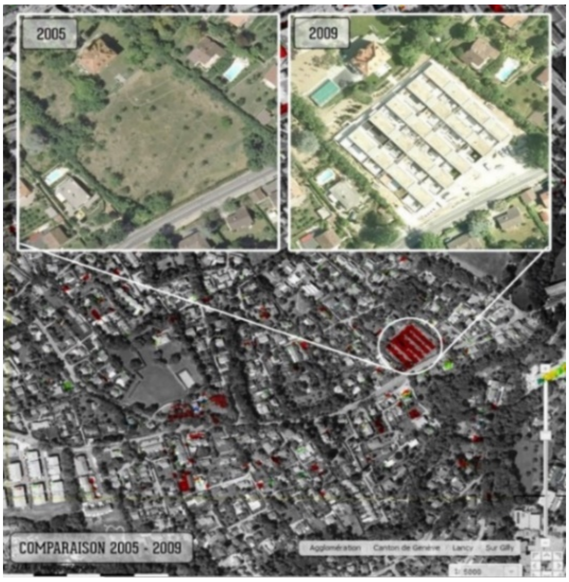

Figure 12. Detection of new constructions, city of Geneva (source : SITG, Genève).

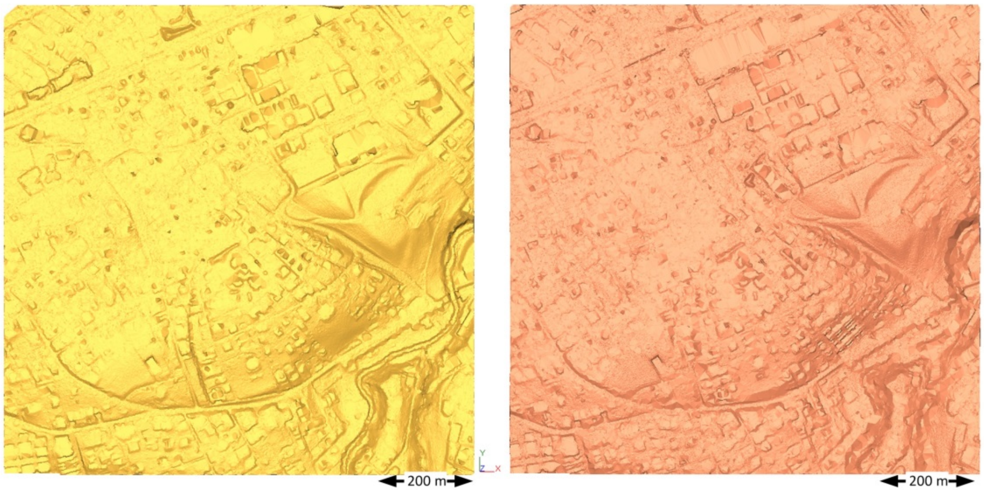

Figure 13. DTM as TIN; 2005 (left), 2009 (right).

Figure 13 shows an example of an urban and natural area of the *Canton de Genève* with DTM derived from laser point clouds and modeled by TIN. Major differences and similarities are highlighted by a simple visual analysis of epoch 2005 and 2009. In order to quantify the height differences, an automated method has been used with the epoch 2005 as reference. If the difference between 2005 and 2009 is from 0 m up to 0.4 m, then the two surfaces are considered equal. If the difference between 2005 and 2009 is from 0.4 m up to 1 m the difference is considered as significant with a residual noise of measurement which is included in this threshold.

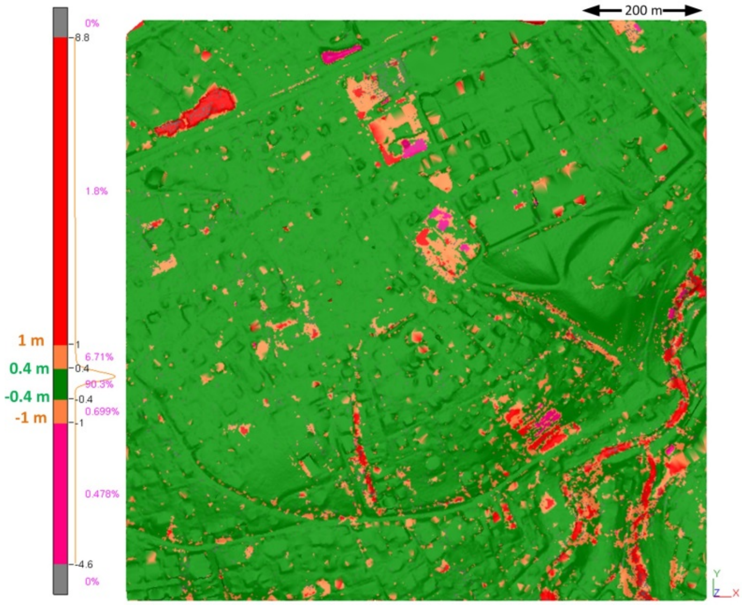

Figure 14. Heights differences
(Green: no changes, Orange: |-0.4-1 m| Red: > + 1 m, Magenta <-1m)

At last if the difference is greater than 1 m then the difference is considered as highly relevant. Figure 14 illustrates the heights comparison between epochs 2005 and 2009. This map shows that more than 90 % of the area as not changed. The color-coded map shows easily the region where the terrain is higher (red) and where it is lower (magenta)

The lower right part of the map is more complicated to interpret. On the one hand we can see important height differences (Figure 14) and on the other hand we can suspect that the model quality is not homogeneous on this natural area (high density of forest and river).

5. Conclusion and Future Development

The teaching unit gathers students and teachers from different backgrounds, which is an advantage for the coordination of teaching actions and for sharing knowledge. This group of competences made possible the data collection of spatial objects, the generation of interpretable maps and the understanding of the evolution of the built and natural environment. Working together is also the best way to learn from other disciplines and to use appropriate methodology and technologies for specific tasks of engineers and architects.

Involving a private company, like Archeotech, is a key advantage for the students because they receive professional advice from a practitioner involved daily in the data acquisition and visualisation of complex objects and areas, and their analysis and understanding.

5.1. Benefits of the Teaching Unit

The ENAC faculty of EPFL has introduced these teaching units in the early 2000 and has regularly encouraged students to work together on interdisciplinary projects. This educational model is not common and needs joint effort to be included in the different curricula. However, this effort has been rewarded in view of the number of initiatives in teaching and research activity. This joint learning process makes sense within the context of the growing complexity of engineering and architectural projects.

5.2. Future Pedagogical Development

The University has to face many challenges in higher education with the growing number of students, the international mobility and the huge penetration of mobile devices. The digital age of education is evolving rapidly and has a deeply impact on the organisation on the teaching activity. On the one hand EPFL is promoting MOOCS for improving the dissemination of knowledge, and on the other hand the institution has to propose more practical oriented labs to the students. Even if the educational models are very different, these two approaches are complementary and offer flexibility in the acquisition of common knowledge (e.g. using a selection of lessons from a MOOC) before doing practical labs which requires several competences. Blended learning is one of the concepts which consist in mixing e-learning, face to face courses and individual labs. In this sense the combination of MOOCS and interdisciplinary teaching units is an adequate response to the concept "*Projeter ensemble*" which gathers students with different skills.

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[4] http://www.aventicum.org/