Bridging Geomatics and Geo-Engineering

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ABSTRACT: Geomatics is the science and technology of the 3D acquisition, processing and visualisation of geo-information, the information which is related to the Earth. The MSc programme in Geomatics offered by TU Delft is jointly operated by three faculties: Aerospace Engineering, Civil Engineering and Geosciences and Technology, Policy and Management. It educates interdisciplinary engineers who will contribute to the entire information chain in a broad range of topics from Civil Engineering and Applied Earth Sciences and among others, in the field of geo-engineering. Because the profile of incoming students is varied, convergence and deficiency courses tailored to individual needs are organised at the start of the academic year. The programme is organised in 3 domains, acquisition, processing and applications. A coherent package of geo-engineering courses is proposed allowing students to link surface observations of the Earth to processes taking place in the ground, and to develop appropriate decision-making tools for land development, early warning systems, etc…

1 INTRODUCTION

Collecting, processing, managing and distributing information and transforming it into relevant support for decision making constitutes the nerve system of society at local, regional, national and global scale. Of increasing importance is information bound to certain locations at, above or beneath the surface of the earth. The tools, techniques and theoretical background for acquiring, processing, managing and disseminating geo-information constitute the discipline of Geomatics.

In September 2005, TU Delft launched a new MSc programme in Geomatics under the hospices of the 3 of its faculties: Aerospace Engineering, Civil Engineering and Geosciences and Technology, Policy and Management. The programme has reached, after several off-site meetings and a period of optimization, a mature stage which is presented in this paper. The preparation of the 2007 external audit of the programme (Qanu 2007) has increased a cohesion to the group of staff members involved in the teaching despite the differences in their background. In contrast to geo-information programmes offered elsewhere in the Netherlands (Wageningen University, Utrecht University, ITC Enschede, and at polytechnic level at Hogelschool Utrecht), the MSc programme at TU Delft builds upon the pool of expertise offered by the three participating faculties to offer a profoundly technical approach to data acquisition, information processing and management and application in the field of Civil Engineering and Earth Sciences, and among others in Geo-engineering.

The paper shows how the coherence of the Geo-engineering courses offered to geomaticians, the definition of attractive multidisciplinary synthesis projects and the inititiation of new inter-disciplines graduation research projects strengthen the bridge between the Master programmes in Geo-engineering and Geomatics.

2 TU DELFT MSC IN GEOMATICSS

2.1 *Historic development*

TU Delft expertise in geomatics originates from a long tradition of education in Geodesy offered over fifty years at both BSc and MSc level until 2004. Since 2005 Geomatics at TU Delft has been offered as a two-year MSc-level programme only, covering acquisition, processing, management and application of geo-information. The programme arises from collaboration between three faculties at the university: Aerospace Engineering, where the portfolio includes acquisition and mathematical processing of geo-information, Technology, Policy and Management, where a GIS technology group specialises in computer processing and geo-information management, and Civil Engineering and Geosciences, covering a

wide area of applications in which decision making relies on geo-information.

The shift from BSc/MSc programme to MSc programme has been seized upon as an opportunity to rigorously revise the contents of the programme, not least in view of new societal and technological developments. As mentioned in the introduction, the programme is unique in the Netherlands and benefits from the individual strengths of the participating faculties and their common drive: the formation of geomatician graduates capable to provide innovative solutions for the civil engineering world.

The programme started in September 2005 with six candidates, three from the phased-out TU Delft Geodesy programme and three from other backgrounds. In September 2006 ten students embarked on the course: eight of whom 'new', four from abroad. In September 2007, the group of seven new participants was strengthened by exchange students, showing the raising international interest for the programme. The target is for thirty new students to enrol by September 2010. The target is realistic. First, the inflow of first year BSc students has increased at the 3 faculties collaborating in the MSc in Geomatics. The faculty of Civil Engineering and Geosciences welcomed in 2007-2008 249 first year BSc students instead of 206 the year before. An effort in marketing and the creation of a 30 ECTS minor in geomatics will catalyse the interest of Civil Engineering students in Geomatics. Second, the Geomatics is very much alive and public interest in geo-information science has never been greater. In 2004 the famous and authoritative journal Nature indicated that geo-information technology belonged to the top three fastest developing disciplines, together with biotechnology and nano-technology. Mobile navigation systems and Google Earth are now 'killer apps'. Media are increasingly interactive and the public is getting used to obtaining information about whatever, whenever: the entire world has become one huge GIS, accessible via the internet.

2.2 *Programme structure and domains*

The two-year programme in Geomatics covers a total of 120 ECTS. At the heart of the MSc Geomatics is the regular programme (table 1), including all subjects that are deemed to be essential for the Geomatics body of knowledge. The core courses (common for all students) and elective courses (differentiating between individual student's interests) are divided into three subject domains (table 2).

Table 1: Structure of the MSc programme in Geomatics

Programme	ECTS
Regular programme	45
Convergence programme *	9 – 15
Elective programme *	11 – 5
Synthesis project	15
Graduation project	40
* Convergence + free elective programme	20

Table 2: The acquisition, processing and applications domains

Course code	Course name	ECTS
Domain 1: Acquisition		
AE4-E02 *	Advanced Remote Sensing	4
AE4-E08 *	Satellite Navigation	4
AE4-E13	Acoustic Remote Sensing and Seafloor Mapping	4
AE4-E14	Radar Remote Sensing and Deformation Monitoring	4
AES1650-07D1#	Shallow Depth Geophysics Theory	4
AE4-E15	Photogrammetry	4
GM1020	3-D Geo-Information Systems	5
GM1010	Reference and Coordinate Systems	4
Domain 2: Processing		
GM1080 *	Geo DBMS	3
AE4-E04 *	Multivariate Data Analysis	4
AE4-E05	Digital Terrain Modelling	4
AE4-E17	Dynamic Data Processing	4
GE4612	Geo Information Infrastructure Technology	4
GE4622	Quality of Geo Information	4
IN4003	Geometric Modelling	6
Domain 3: Application		
GE4662 *	Organisational and Legal Aspects of Geo Information	4
AE4-E07 *	Location Based Services	4
GE4732	Spatial Information in Utilities	4
AES1710 #	GIS Applications in Engineering Geology	3
CT4450	Integrated Water Management	4
CT4801	Transportation and Spatial Modelling	6
CT4300	Introduction to Coastal Engineering	4
CT5401	Spatial Tools in Water Resources Management	3
Free Electives		
IN4151	3D Computer Graphics and Virtual Reality	6
IN4010TU	Artificial Intelligence	6
AES1660 #	Subsidence	2
AES1650-07D2 #	Shallow Depth Geophysics Fieldwork	2
CT4260	Building Informatics	4
CT4330	Ports and Waterways 1	4
CT4340	Computational Modelling of Flow and Transport	4
CT4431	Hydrological Models	4
CT4460	Polders and Flood Control	4
CT4821	Traffic Flow Theory and Simulation	4
CT4831	Data Collection and Analysis	4

* core course
# course of the geo-engineering package

Domain 1 concerns a systematic and geodetically sound approach to data acquisition and information extraction, covering surveying, satellite positioning, photogrammetry and remote sensing from terrestrial, marine, airborne and space-borne platforms, based on optical, laser, radar and acoustic and seismic sensors. The core courses consist of satellite navigation and advanced remote sensing; electives are listed in Table 2. Preprocessing, to prepare the data for information extraction, is also covered in this domain.

Domain 2 concerns an information systems approach to storage, processing, management, dissemination and visualisation of data and information, based on Data Analysis methodology and Spatio-temporal Database Management Systems technology. Geo-information is transformed into object representations and made suitable for decision making. The core courses consist of Geo-database management systems and Location-based services; electives are listed in Table 2.

Domain 3 concerns the role of geo-information in decision-making within a broad spectrum of the fields of Civil Engineering & Geosciences, covering design & construction, hydraulic engineering, water management, transport & planning and geotechnology. Students get an appreciation for the similarities as well as the differences in the geo-information aspects of these applications.

To ensure a proper balance between breadth and depth, students are expected to put a certain emphasis on either acquisition or processing through their choice of track. Additional free elective courses allow for deepening or broadening knowledge. The choice of track does not influence Domain 3, which contains also two core courses, Organisational and Legal Aspects of Geo Information and Location Based Services in addition to which two elective courses have to be chosen.

2.3 *Convergence programme*

The Geomatics MSc programme is designed to be attractive for students from a variety of backgrounds, obtained in BSc programmes at different faculties within TU Delft, or from other universities in the Netherlands and abroad. For talented BSc-level graduates from related polytechnic programmes, the Geomatics MSc provides an opportunity to progress to academic level. For all students, including students from developing parts of the world, holding a MSc in Geomatics is an asset given the importance of geo-information during infrastructure development, management of natural and earth resources, water management, and urban development.

To ensure that all candidates have a common base of knowledge and skills when entering the regular Geomatics programme, a convergence programme is offered in the first semester. The convergence programme consists of four modules in different subject areas, as shown in the table 3.

The module GIS Principles and the module Data structures, Algorithms & Databases are compulsory for all students. They concern geo-statistics and probability and DBMS, CAD, computer graphics, spatial data structures and algorithms respectively. To accommodate candidates with different levels of prior knowledge in those subject areas, these modules are offered at two different levels: a beginner's level for novices in those fields, where the necessary principles are taught, and an advanced level where suitable candidates may demonstrate the knowledge and skills and gain additional experience by executing an assignment. During an intake session the suitable level is determined on a personal basis.

The modules Adjustment Theory and Introduction to Remote Sensing are meant for candidates with no or only limited prior education in these subject areas. They cover reference systems, cartographic projections and basics and physics of remote sensing respectively. They are offered at beginners level only, and may be omitted by others, as determined in the intake session.

The convergence modules are part of the Geomatics programme, and therefore ECTS points gained during the convergence programme contribute to the requirements (120 ECTS) for obtaining the Geomatics degree.

A distinction is made between deficiency, which is a lack of knowledge of general and predominantly mathematical subjects, and convergence, a lack of Geomatics knowledge. Before embarking on the programme candidates are expected to have prior knowledge of mathematics, including differential and integral calculus, linear algebra, matrix theory and elements of numerical analysis. Candidates not fulfilling these requirements are entered on a 'deficiency' programme, extending the total time needed to complete the MSc in Geomatics.

2.4 *Free elective programme*

A student may use the time available for free electives (table 2) to:

- Further deepen the knowledge within the selected track, by choosing remaining elective courses in the corresponding domain;
- Broaden his/her views by choosing elective courses in the alternative domain;
- Broaden his/her application knowledge by choosing from the remaining elective courses in Domain 3;
- Deepen a certain application by choosing from the free elective courses in Domain 3.

Table 3: Convergence courses

Name	ECTS	For whom?	Period
GIS Principles	3	Compulsory 2 levels: beginner / advanced	1
Datastructure, Algorithms & Databases	6	Compulsory 2 levels: beginner / advanced	1/2
Adjustment Theory Introduction	3	When required single level	1
Remote Sensing	3	When required single level	2

2.5 *Synthesis project*

In the 2nd year of the Geomatics master programme all students participate in a synthesis project. Groups of approximately 5 students cooperate in a project (15 ECTS). Most of the subjects taught in the master programme should be combined in the synthesis project: GIS, positioning and navigation, photogrammetry, remote sensing (optical, laser, acoustic, radar), mathematical geodesy, spatial databases, hydrology, infrastructures (civil engineering), engineering geophysics, location based services, etc…

The synthesis project provides a synopsis of the different disciplines and aims at practising teamwork in small groups. This exposes students to the entire chain, from project definition, acquisition, data processing and analysis, presentation and delivery to application, working in a team within an interdisciplinary environment and understanding how the results of the geo-information process are used and applied. In addition, the synthesis project stimulates collaboration between staff of the groups involved and emulate a constructive competition between the groups for defining/supervising/controlling a project. Examples of synthesis projects bridging between geomatics and geo-engineering are given in section 2.

2.6 *Graduation project and internship*

The graduation project is an individual research assignment, executed under the guidance of a graduation professor and one or two supervisors. Given the multi-disciplinary and application-oriented emphasis within the MSc programme, definition of graduation research topics that have a clear relation to an application will be strongly encouraged, with interfacultary supervision teams. Executing research for graduation projects in organisations outside the TU Delft is also appreciated.

The Geomatics programme does not contain an internship as a compulsory element. Participants can choose, however, to complete an internship voluntarily. Under the condition that the internship is sufficiently research oriented, the examination committee may decide, upon motivated request, that it should be accepted as a partial fulfillment of the graduation project research. If chosen, an internship report is required, to be graded by the supervision team.

3 GEO-ENGINEERING AND GEOMATICS

3.1 *Package of Geo-engineering courses*

Geomatics students can articulate their individual programme in order to gain expertise in a number of applications. They can achieve such a goal by taking, for example, the coherent package of courses offered by the Geo-Engineering section (see courses with subscript # in table 2). These courses allow Geomatics students to link surface observations of the Earth to processes taking place in the ground, often notorious for its heterogeneity and to develop appropriate decision-making tools for land development, early warning systems, etc…

It is assumed that students opting for the Geo-Engineering course package have a vivid interest in Applied Earth Sciences and have followed at least a geology course (for engineers) in their BSc programme and/or read text books such as Earth Dynamic Systems by Kenneth Hamblin and Eric Christiansen and Foundations of Engineering Geology by Tony Waltham.

With Shallow Depth Geophysics- Theory, Earth observation is prolonged to the subsurface. The course explains how, in theory, the shallow subsurface can be characterised by quantitative physical methods, especially by seismics, both onshore and offshore (including sea floor mapping) and electromagnetism.

Participants to Shallow Depth Geophysics- Fieldwork design their own geophysical survey, acquire and process their own field data sets and integrate them with other geo-data (remote sensing, geomorphological, geological and geotechnical data) for a real civil engineering project. In the last years, students proved the added value of geophysics for motorway widening and dike strengthening in the Western Netherlands.

With Subsidence, the reaction of the Earth's surface to the extraction of solids or fluids from the subsurface is described and predicted in time and space. A wide range of human activities associated to subsidence are considered: oil, gas and water production; mining with different techniques like longwall mining, room and pillar mining, solution mining; closure of mine workings and shaft. Potential damages are estimated and mitigation measures are proposed. The course also covers natural subsidence, its causes and the detection of natural subsidence phenomena. It explains how, by means of a site investigation specific to subsiding areas, hazard maps can be made to reduce the risk to an acceptable level. Attention is also paid to the communication of geo-risks to the public and concerned organisms and the elaboration of an environmental impact state-

ment. All course participants are invited to join an excursion to Maastricht, the Netherlands and Liège, Belgium. In Maastricht, they are exposed to the collapse of room and pillar mines (figure 1) and the subsequent subsidence. In Liège they predict the spatial and temporal development of dolines due to the shallow dissolution of limestone in an syncline in a residential area (figure 2).

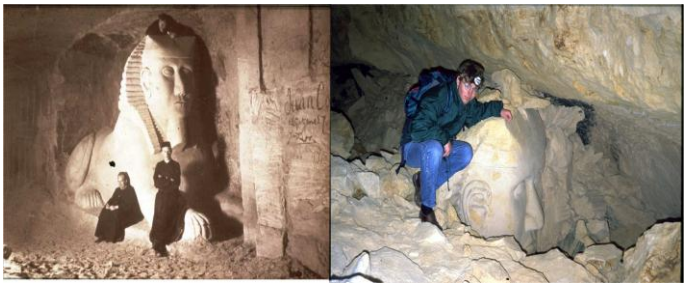

Figure 1: Exposure to room and pillar mine collapse. The Sphinx before and after the 1920 large scale collapse of the Fallenberg mine in Maastricht, the Netherlands (left, Archive Stichting Jezuietenberg, right, (Bekendam, pers. Comm.)

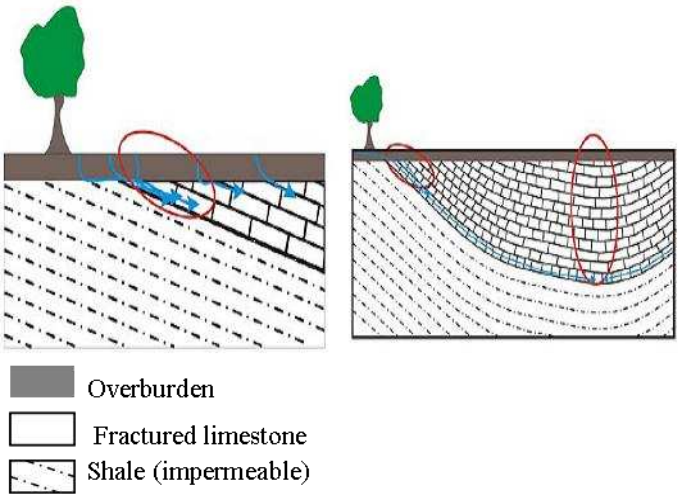

Figure 2: Predicting the spatial development of karts features around Liège (in red). "Karst features are often found were an impermeable layer and a LST layer meet at the surface. Further downwards along the contact between this "impermeable" layer and the LST, karst does not develop further because the infiltrating water is saturated by Ca2+ at a certain depth. If a syncline is present, water will accumulate in the axis of this syncline. Above this axis karst features are known to develop as well." (Schmitz & Schroeder 2004).

The GIS in Engineering Geology course is primarily intended to provide a working knowledge of how GIS may be used to manage and analyse spatial information concerning engineering geology. Examples are drawn from the experience of the lecturer in the fields of ground investigation and geohazard assessment. The principles are equally applicable to other geotechnical situations where spatial controls are important. The course concentrates on a PC-based system (Idrisi for Windows), and emphasises the raster (cell- or pixel-based) GIS data structure. It includes an overview of hazard assessment and risk analysis using GIS databases and is supplemented by a practical project in which geohazards are identified and assessed using basic engineering geological information.

Students can capitalise on their geo-engineering knowledge by taking a number of civil engineering courses related to ground engineering and geology such as Introduction to Coastal Engineering or Polders and Flood Control.

3.2 *Synthesis project*

The first synthesis project was executed in September-October 2006 with as its subject the use of PS-InSAR (Persistent Scatterer Interferometric Synthetic Aperture Radar) for monitoring deformation of dikes (figure 3). The results of the project received national media attention! The project underscored the necessity to understand processes taking in the subsurface to design robust and efficient early warning systems for dike failure and emphasized the potential of jointed research between geo-engineering and geomatics staff members. The subject of the synthesis project changes every year. The Geo-Engineering and the Coastal Engineering sections are currently elaborating with the help of the Dutch dredging industry a proposal for assessing the spatial impact and longevity of beach nourishment along the North Sea coast. Several techniques ranging from onshore and offshore geophysics, geotechnical investigation, terresterial laser scanning, video camera control to satellite remote sensing will be used to feed data-driven and process-based models developped at TU Delft.

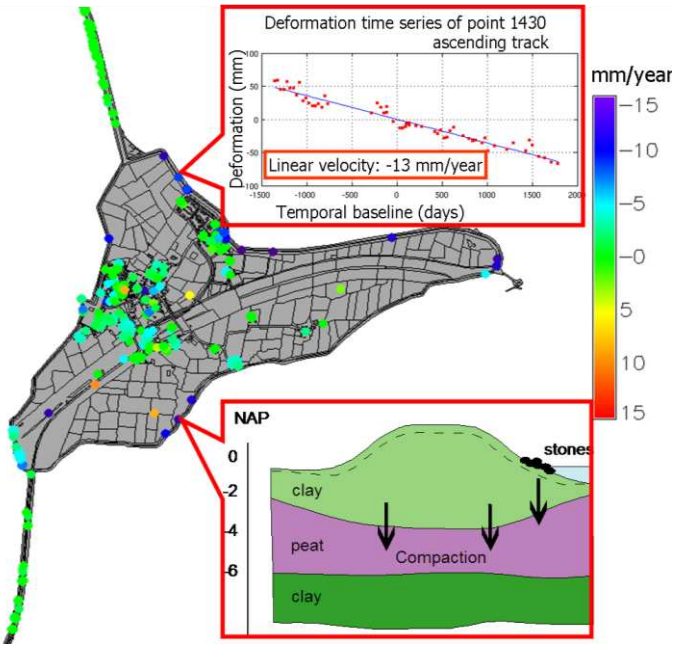

Figure 3: Monitoring dike deformation with PS-InSAR. "Due to the compaction of their underlying peat layers, the dikes in Marken have settled of about 10 cm between 1992 and 2001." (Dentz et al. 2006))

3.3 *MSc graduation thesis*

Exposure to the field of geo-engineering can be further developed during the 40 ECTS graduation project, where integration of knowledge and independent judgment culminate. Current graduation projects co-supervised by geomatics and geo-engineering staff include the tracking of geological features on aerial laser altimetry data in the Western Netherlands and the extraction of ground parameters (discontinuity orientations and multi-scale roughness) from terresterial laser scanner for slope stability analysis.

4 CONCLUSION

Graduates of Geomatics from the TU Delft will be able to deliver valuable technological and methodological contributions to industry and public sector and to society in general in all domains concerned with the production, management, dissemination and application of geo-information and in particular in the field of geo-engineering.

A package of geo-engineering courses initiates geomatics students to subsurface characterisation, response of the Earth Surface to natural and man-made disturbances and GIS applications in Engineering geology for the identification and mitigation of geo-hazards. Synergy between geo-engineering and geomatics is increased by field excursions, graduation projects co-supervised by both groups and the definition of attractive multidisciplinary synthesis projects.

During their Masters, geomatics students become familiar with geo-information issues in geo-engineering and a number of other applications. They appreciate similarities as well as differences between geomatics-related issues in those fields, and are able to judge the possibilities and limitations of expanding the application of methods, techniques and practices across applications.

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