NEXT GENERATION SMART CITIES - THE ROLE OF GEOMATICS

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ABSTRACT:
More than half of the global population lives in urban areas. This will increase to 70% by 2050. Urban growth is most rapid in the developing world, where cities gain an average of five million residents every month. As cities grow in size and population, harmony among the spatial, social and environmental aspects of a city and between their inhabitants becomes of paramount importance. This harmony depends on several cornerstones: sustainability, wealth and justice.
Since a number of years the issue of "Smart" Cities is being used both as buzzword and technical term to indicate the urgent need of change in the development and management of cities. In this context the "Spatial intelligence" of cities plays an important role. It refers to informational and cognitive processes, such as information collection and processing, real-time alert, forecasting, learning, collective intelligence, distributed problem solving, which characterize "intelligent" or "smart" cities.
Here Geomatics technologies and know-how become crucial elements in developing such concepts and maintaining them over long periods of time. Geomatics is understood as the unity of Geodesy, Surveying, Photogrammetry/Remote Sensing, Spatial Information Systems, Visualization/Cartography.
This paper, after a brief definition of the smart city concept, will describe to what extent Geomatics technologies can contribute to the realization and advancements of smart cities. As example and test-bed we will use the currently active SEC-FCL project (**S**ingapore-**E**TH **C**entre for Global Environmental Sustainability - **F**uture **C**ities **L**aboratory). This project has nine research streams (modules): Urban Sociology, Low Exergy, Landscape & Ecology, Digital Fabrication, Transforming and Mining Urban Stocks, Territorial Organization, Mobility and Transportation Infrastructure, Urban Design Strategies, and Simulation Platform. The Simulation Platform is the place where Geomatics and other data for all the other modules are being generated, analyzed and simulated. A new installation, the Value Asia Lab, serves as interface for interactive visualizations and simulations.
Among the many Geomatics technologies our paper will focus on 3D city modeling. With projects in Punggol and Little India, both districts of Singapore, we will show how high-resolution stereo satellite images are used in city modeling.
The major part will deal with the derivation of a very high resolution model of the NUS (National University of Singapore) campus from 5 cm footprint aerial UAV images, Mobile Mapping System laser-scan point clouds and terrestrial images. This is a very complex problem to be solved. We show work in progress.

1. INTRODUCTION

For the first time in human history, more than half of the global population lives in urban areas. This will increase to 70% by 2050. Shanghai's population has almost doubled in a decade, from less than 13 million residents in 2000 to an estimated 23 million today, and by 2050 it is expected to exceed 50 million. Cities cover just 2% of the Earth's surface yet consume about 75% of the world's resources. So it becomes obvious that cities are the key element when coping with climate change and reduction of use of resources. Since city growth can hardly be avoided, one must be able to cope with its consequences. Here it is essential that harmony exists or is generated among the spatial, social, economical and environmental aspects of a city and between their inhabitants. This harmony hinges on 3 key pillars: Earth environment, economic development and social equity. These pillars are balanced through sustainability. In this context the concept of a SMART city has emerged. Usually "smartness" is expressed by its 6-axes model: smart economy, mobility, environment, people, living, governance. Only if all these elements are in balance a city can fulfill its request for sustainability and quality of life. In other words, a city can be called 'smart' if investments in human and social capital and traditional (transport) and modern (ICT) communication infrastructure will fuel sustainable economic development, a high quality of life, with a wise management of natural resources, through participatory governance.

A smart city possesses spatial intelligence**.** This summarizes all components in terms of brain-, hard- and software which are required to manage a city efficiently with the goal to sustain high quality of life over a long period of time (resilience). As such it refers to informational and cognitive processes, such as information collection and processing, real-time alert, forecasting, learning, collective intelligence and distributed problem solving. In this environment the Geo-Spatial Information Sciences play a key role, providing for the underlying theoretical framework and practical procedures for data acquisition, processing, analysis and representation.

Traditional methods of planning and managing cities do not work anymore in this new environment. New approaches are necessary. While interactive design and planning will still be of need and value, computerized techniques must find more interest. It is generally agreed that context is a key element in the design of future new and the transformation of existing cities. Context must include societal, governmental, economic and technological components. This context must be transformed to and modelled in the digital (computer) domain. The so created models must be supported and activated by data. The complexity of the political, social and economic decision-making processes requires precise, reliable, actual and largely complete data. Most of this data is spatially related. This clearly emphasizes the relevance of the Spatial Information Sciences, especially also Geomatics, for any future-oriented design and planning process.

Li et al., 2013 are presenting an overview dealing with "*Geomatics in Smart Cities – Concept, Key Techniques and Applications".* They outline the current shift from Digital Cities to Smart Cities. They see Digital Cities, The Internet of Things and Cloud Computing as important supporting technologies for Smart Cities and discuss how these technologies can be implemented and then will contribute to a better management of cities. As new technologies for Smart Cities they describe briefly the location cloud, remote sensing cloud, integration of video and GIS, integration of space-borne, air-borne and terrestrial sensors and GIS, indoor and underground navigation, ubiquitous sensing via smart phones and spatio-temporal data mining. Finally they show four concrete “smart” applications in Wuhan and Sichuan: Smart municipal supervision, smart transportation, smart environment monitoring, smart tourism.

Wang, 2013 describes the role of GIS in a Smart City context. He clearly emphasizes the advantages that modern GIS technology brings to the Smart City and underlines this with examples from transportation and mobility, risk management, urban planning, noise mapping and solar energy. Under the term “Interdisciplinary Urban GIScience” he addresses issues from volunteered geographic information collection, cloud computing and SDI and geo-visualization and human-computer interaction. With the help of GIS cities have already succeeded in transforming their managements to a more efficient level. Yet, much remains to be done to make full use of the potential of modern GIS.

Actual, accurate and complete data is very crucial for designing, modeling and planning in Smart Cities. Geomatics always has played a significant role when it comes to reality-based data acquisition and processing. The present times are characterized by the availability of a great amount of different sensors for a variety of data collection activities.

Laser-scanners, both from the aerial and terrestrial platforms play a very important role in today’s fast data collection scenery. Huang, 2013 gives an account of the state-of-the art in airborne laser point cloud processing for the purpose of generating 3D city models, in particular buildings. The overall process of modeling from point clouds is split up in detection, feature extraction and 3D model generation. A particular point of discussion is the quality control of the results of otherwise automated procedures. Standard methods for quality evaluation are still missing. While raw data acquisition with aerial and terrestrial platforms is very fast today, there are still many bottlenecks in data processing, considering the pipeline from unstructured point clouds to structured surface models.

Another approach for reality-based modeling is via the use of images. Mueller-Arisona et al., 2013 investigate a new method of combining reality-based 3D models, generated from images, with procedural (generic) modeling in a single workflow, in order to derive high quality/higher resolution hybrid building models. They show how the approach increases the level-of-detail and texture quality compared to using photogrammetry alone, and how their methodology is applicable in practice in terms of a concrete case study based on satellite imagery and terrestrial façade photographs. As project example serve the new-town building towers in Singapore’s Punggol area. In this project context two leading software packages are used: Cyber City-Modeler for reality-based modeling and City Engine for procedural modeling.
This paper will, starting from a brief description of goal and set-up of the SEC-Future

Cities Laboratory, describe the ever increasing role that Geomatics plays in this context. This role is not only related to raw data acquisition, but also to data administration in data bases, processing, analysis, and representation. We also emphasize the importance of Geomatics for the SEC-FCL project in Singapore.

In a second part we show with a few examples some of the products that Geomatics can deliver. We derive 3D city models from high-resolution stereo satellite images. We also report about our project of collecting very high resolution (5 cm footprint) aerial images by flying with a UAV over the campus of NUS (National University of Singapore). We then combine the aerial data with laser-scanned terrestrial point clouds, produced by a Mobile Mapping System, in order to produce a complete city model, showing also the façades in 3D.

2. SEC-FUTURE CITIES LABORATORY

In Schmitt, 2012 the "Digital Chain" is promoted, which is a concept of data acquisition, data handling and decision making on an architectural scale, involving design, construction and facility management of buildings. This "digital chain" is reflected in the concept and work of the **SEC-Future Cities Laboratory**. The Singapore-ETH Centre for Global Environmental Sustainability (SEC) was established by ETH Zurich and Singapore's National Research Foundation (NRF) in 2010. It is an institution that frames a number of research programmes, the first of which is the Future Cities Laboratory (FCL).The SEC strengthens the capacity of Singapore and Switzerland to research, understand and actively respond to the challenges of global environmental sustainability. It is motivated by an aspiration to realise the highest potentials for present and future societies. SEC serves as an intellectual hub for research, scholarship, entrepreneurship, postgraduate and postdoctoral training. It actively collaborates with local universities and research institutes and engages researchers with industry to facilitate technology transfer for the benefit of the public. The FCL is a highly trans-disciplinary research centre focused on urban sustainability in a global frame. It is home to a community of over 100 PhD, postdoctoral and Professorial researchers working on diverse themes related to future cities and environmental sustainability. For details see http://futurecities.ethz.ch. Within this project a city is seen as an urban metabolism, and the concept of stocks and flows is used to describe and analyse its status and dynamics. This is done on three different levels of scale: S (small)-scale: the individual building, M (medium)-scale: the urban part and L (large)-scale: the territory. Ten different research modules investigate into stocks and flows of energy, materials, capital, people, water, space and information. The information part is treated on the Simulation Platform. Its goal is to support design and decision-making processes with new techniques and approaches to data acquisition and processing, information visualisation and simulation. The Simulation Platform currently encompasses more than 20 researchers. Figure 1 shows the research modules of the SEC-FCL project in Singapore. The Simulation Platform models information in terms of stocks and flows and assembles and produces data needed by the other modules for storage, processing, analysis, visualization, animation.

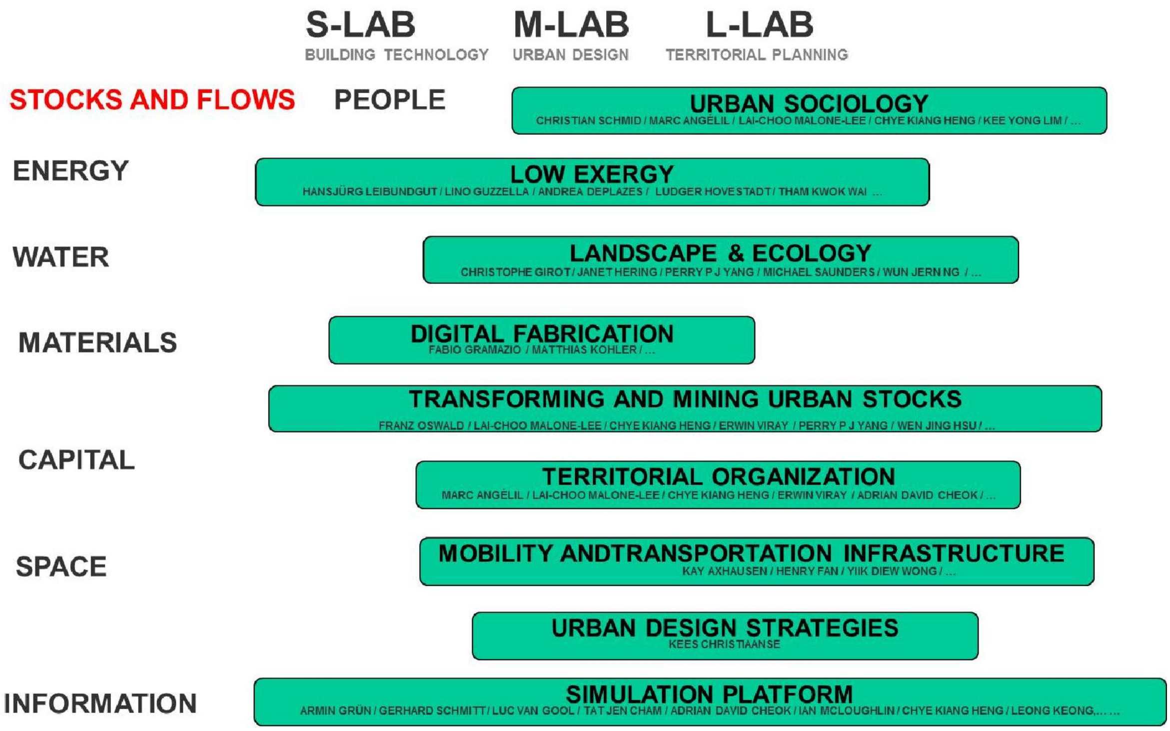


Figure 1. Research modules of the SEC-FCL project in Singapore. Geomatics procedures are implemented on the Simulation Platform, but also support the other modules (cc: SEC-FCL).

3. ROLE OF GEOMATICS

The "digital chain" may also serve as a synonym for the role that Geomatics plays in the context of Smart Cities. If we understand Geomatics as the science of acquiring, modeling, analysing and representing spatially-referenced data, then it integrates as key disciplines Geodesy, Geodetic Mensuration, Photogrammetry and Remote Sensing, Cartography and Geoinformatics. Much of the work of the SEC-FCL Simulation Platform is concerned with Geomatics issues. Some of the Geomatics-related R&D topics of the Simulation Platform are:

- Automatic or semi-automated generation of Digital Surface Models (DSM) from satellite, aerial and terrestrial images and/or LiDAR data
- Further development of the semi-automated techniques (like CyberCity Modeler) onto a higher level of automation
- Integrated automated and semi-automated processing of laser-scan point clouds and images, both from aerial and terrestrial platforms
- Streamlining the processing pipeline for UAV image data projects
- Exploring the various applications of UAV-based thermal imaging
- Set-up of GIS with 3D/4D capabilities
- Change detection and updating of databases
- Combination of real and synthetic (e.g. planned) objects (reality-based and

generic modeling) - see CC-Modeler and City Engine
- Handling of dynamic and semantic aspects of city modeling and simulation.

This leads to 4D city models
- LBS system investigations (PDAs, mobiles)
- Establishment of a powerful visualization and interaction platform ("Value Lab Asia")

Figure 2 shows the research work packages of the Simulation Platform. From the topics it becomes clear that Geomatics plays a key role there.
Besides its own R&D program the Simulation Platform has a distinct service function with respect to all other SEC-FCL modules and scientists. A major component of this service function is the maintenance of a GIS and the training of other researchers in GIS-related topics.

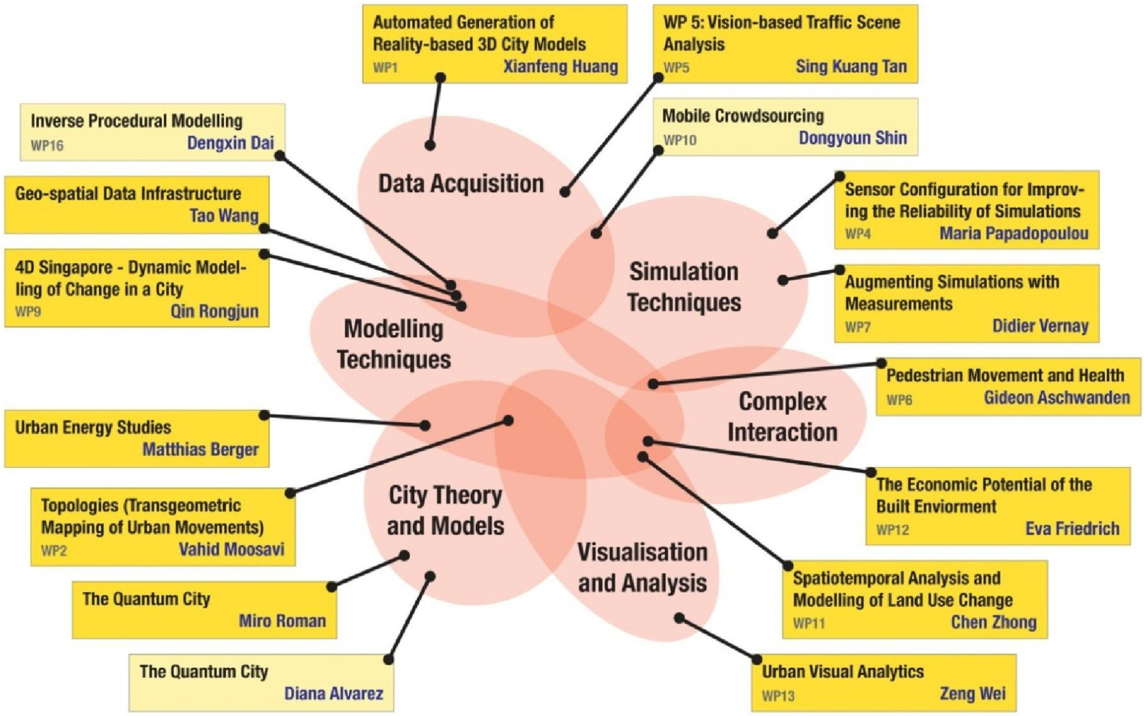


Figure 2. Work packages of the SEC-FCL Simulation Platform (cc: SEC-FCL)

Currently, the GIS database includes data from Singapore (and partly from Indonesia, Thailand, China and Malaysia) like:
+ 3D city models of Rochor, Punggol and NUS campus
+ DTM, DSM at different resolutions
+ Master plans in vector format
+ Land use map, drainage patterns
+ Buildings: coordinates, building type, number of floors above and below ground, number of flats and rooms, roof type and shape, type of ownership, value (insured value/ market value), status of protection as heritage, life cycle of the lot/buildings, age
+ Thermal building data

+ Historical plans/cadaster
+ Census data 2010 with location
+ School catchment areas
+ Navteq road network
+ Georeferenced post codes
+ Climate/weather data, temperature of ground at various depths, annual temperatures of rivers and ocean

Besides above, the database also includes 40 layers of POIs, Singapore address points, Singapore detailed control plans and Google images.

Among all the Geomatics technologies we can address in this paper only a few more in detail. 3D city modeling is of course of crucial importance. 3D city models may serve many purposes, as for instance environmental monitoring, planning (buildings, roads, location), mobile communication, LBS, energy (solar), natural hazards, tourism, real estate, architecture, landscape engineering, monument preservation, smart homes, insurances (risk transports, etc.), 3D car navigation, homeland security, police, fire-squad, traffic and crowd control.

4. 3D CITY MODELS FROM SATELLITE IMAGES

It is a particularity of Singapore that aerial images are not available, they are still highly classified. Therefore we have produced 3D city models for some areas of interest from high-resolution satellite images. The sub-pixel georeferencing accuracy of both projects is described in Wang and Gruen, 2012.

We have generated 3D models for the traditional shophouse-dominated district Rochor ("Little India") from IKONOS stereo-images and for the newly built-up area Punggol from WorldView-2 stereo-images. Figure 3 shows the geometry model of Rochor, overlaid by cadastral map data. This model is used in a large multi-module research study called Rochor+. The Rochor+ district displays probably the largest diversity with respect to its urban morphology and its social composition in the whole of Singapore. This abundance of variation makes the district a specimen of study to some of the modules. Therefore 15 researchers from 5 different modules have chosen the district as research area. It is expected that this urban system can make a crucial lesson for Singapore's future developments.
Figure 4 shows a view onto a part of the Punggol model, which carries texture from satellite images on the terrain and on the roofs. The Punggol area is of totally different type. It is a newly built district which will finally house about 350 000 people, roughly the size of Zurich, Switzerland. It is a special case of urban planning, where mainly flats for lower income people were planned and are built. Also the functional mixture is unique with over 97% of the built area residential in a high-rise typology, currently without hotel or theater. The area is designed for living and offers recreational facilities, but no commercial or industrial functions. The occupants

therefore have to commute to work, which puts a heavy additional load on the transportation system.

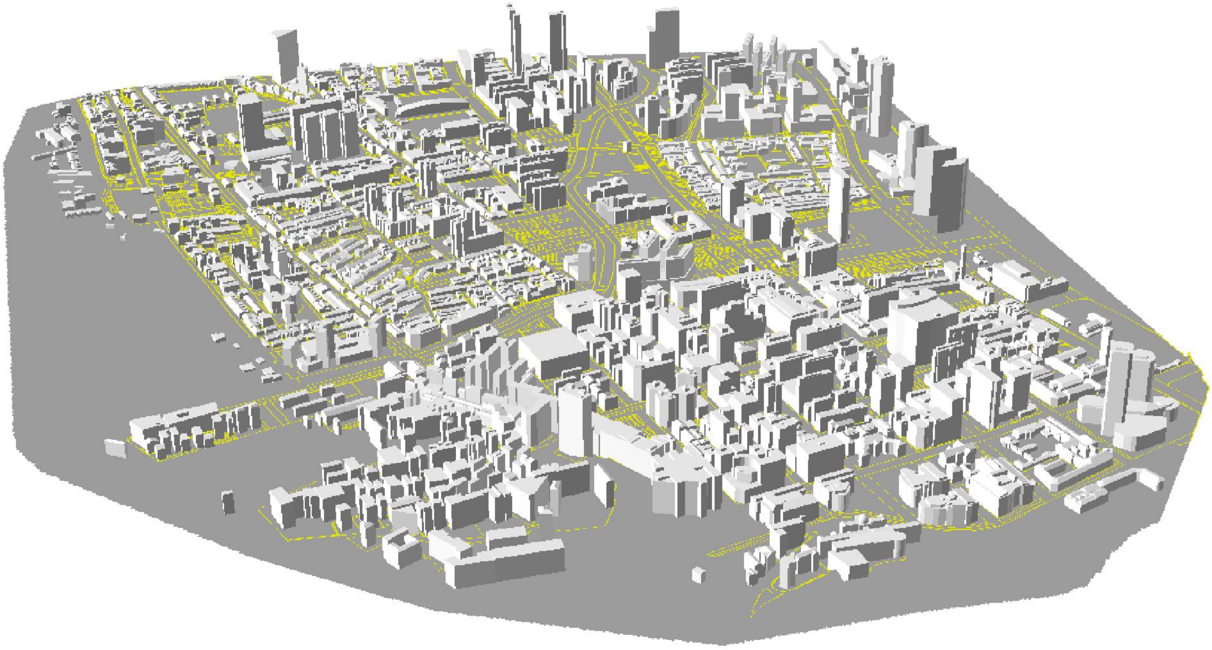


Figure 3. 3D model of Rochor ("Little India"), derived from an IKONOS stereo-model using CyberCity Modeler, with an overlaid cadastral plan.

Figure 4. Partially textured 3D city model of Punggol, Singapore. The model was derived from a WorldView-2 stereo-model by using CyberCity Modeler.

5. VERY HIGH-RESOLUTION 3D MODEL OF THE NUS CAMPUS

A major effort was devoted towards setting up a pilot project with the goal to collect very high resolution data of various types (images and point clouds) over the NUS (National University of Singapore) campus area. With this data methods of 3D data processing for city model generation should be exercised and further developed and refined.

The input of our work is: (1) raw point clouds from a Mobile Mapping System (MMS); (2) UAV images; (3) few Ground Control Points (GCPs), (4) optional: Terrestrial images for geometric modeling of façades and texture mapping.

The UAV part of the project is described much in detail in Qin et al., 2012, while the integrated processing of aerial and terrestrial image data and laser-scan point clouds from a Mobile Mapping mission is addressed in Huang et al., 2013. From this last publication we take the main workflow of this project as (see also Figure 5).

(a) Aerial triangulation of UAV images
(b) Integration of UAV-derived control point data to geo-reference and adjust the MLS point cloud data
(c) Modeling of the roof landscape from UAV images
(d) Measurement of the DTM from UAV images
(e) 3D modeling of façades from MLS data and (if needed) from terrestrial images
(f) Modeling of DTM from MLS data
(g) Fusing façade and roof models and the DTMs to generate a complete geometry model
(h) Optional: Texture mapping from aerial and terrestrial images

The complete procedure is shown in Figure 5. From the input image data, control points and raw point cloud data we can derive a complete 3D site model, achieved by integration of these input data sources. One of our byproduct is a precisely georeferenced point cloud from raw data without much field work.

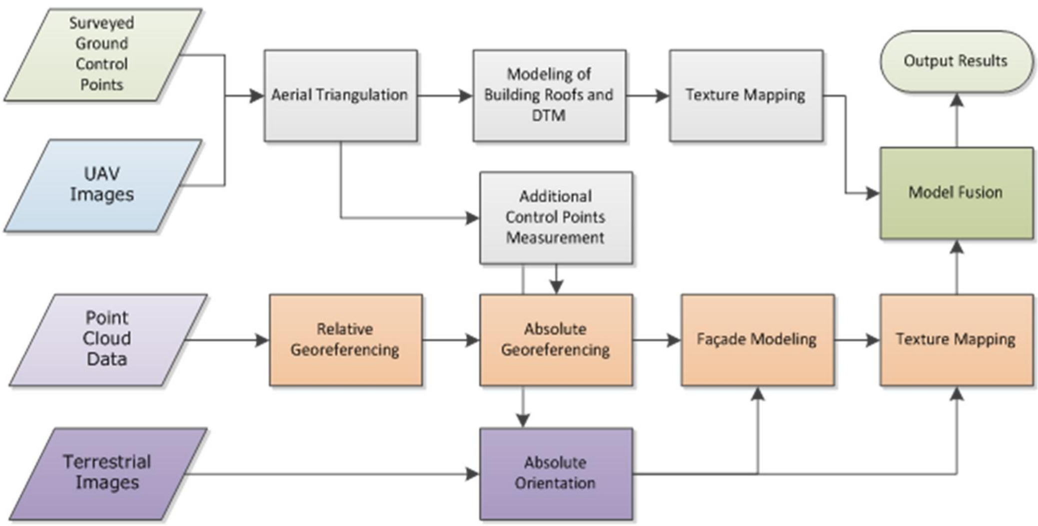


Figure 5. Flowchart of integrated data processing

5.1 UAV data over NUS campus

The modeling area covers approximately 2.2 km^2. This may not be a large area in mapping, but considering the restricted flying height of 150 meters and a camera constant of 16 mm with off-the-shelf cameras, we obtained 857 images in total with a pixel size of 5 cm. There was another restriction concerning the flight: the UAV was not allowed to fly across the major public roads and should stay strictly within the campus boundaries, which splits the whole areas into 3 parts. This required the flight path to follow the border of the campus closely.

The AscTec Falcon 8 was used for the mission. It is a two-beam octocopter with 4 rotors on each side, powered by battery. It has a build-in GPS/IMU, barometer, electronic compass and stabilizing system for both the camera and the platform. It has up to 300 meters remote controlling distance with a maximal operation slot of 20 minutes. Since the octocopter needs some power to keep operating, one of the biggest disadvantages is the short operation time. Due to signal disturbance and unexpected circumstances like strong wind, loss of connection, etc. we only took maximal 25 images per flight for safety reasons, sometimes even less, especially when the flight was taken near the boundary of the mapping area. Figure 6 shows such a small sub-block.

Figure 6. A 4x4 sub-block of the NUS UAV campus block

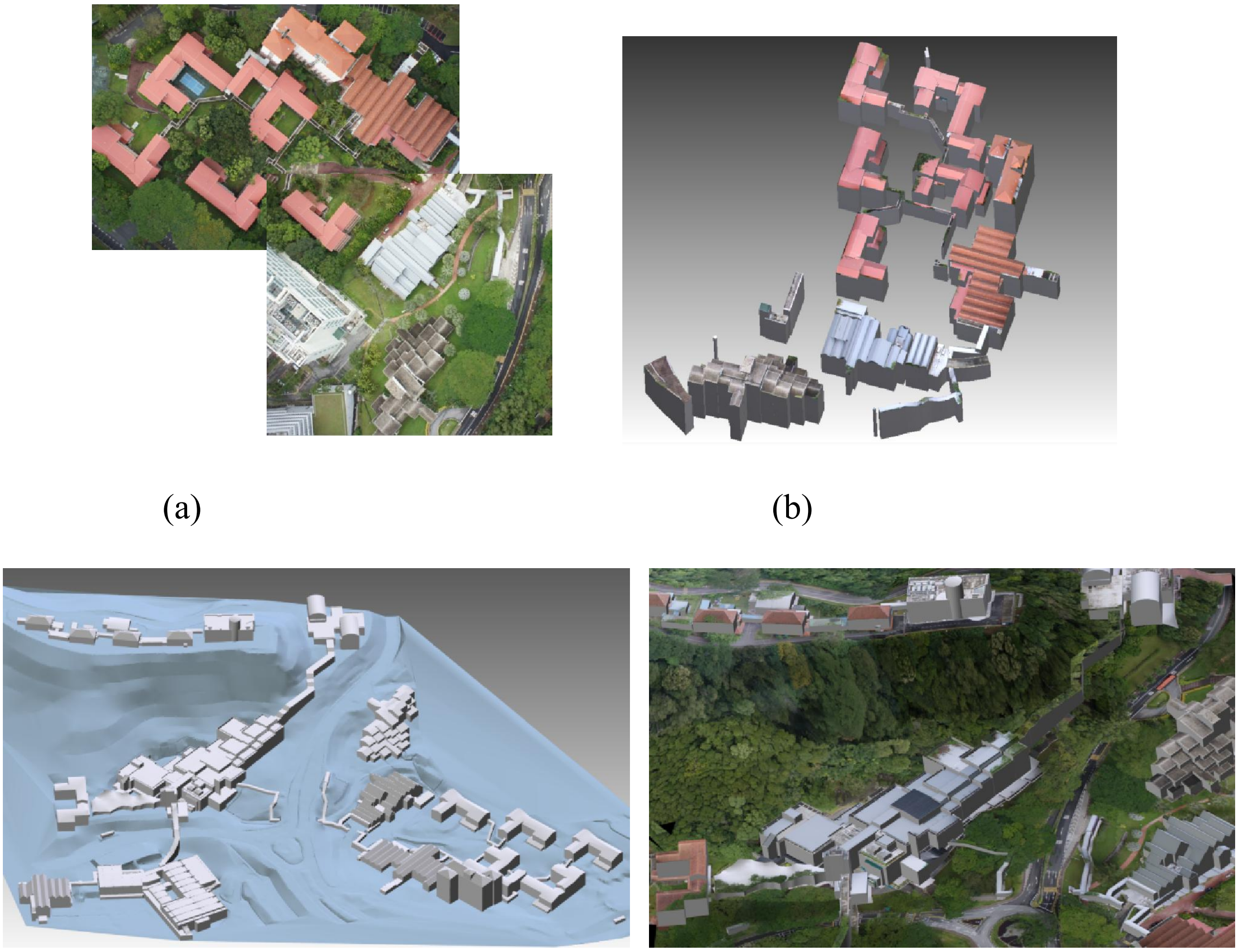
The first step in data processing is georeferencing/triangulation. Due to the limit of flying only small sub-blocks at a time, the complete block of 857 images actually consisted finally of 47 small sub-block units. This unconventional block structure and other particularities caused many problems with commercial software and it took us some time to finally find two software packages which delivered reasonable results (APERO and pix4D).

We measured in total 39 GCPs by GPS. 11 of those points served as check points in order to have some external accuracy check, while the rest (28 points) were used as GCPs in triangulation. With the fully automated triangulation software APERO (Pierrot Deseilligny and Clery, 2011) we received quite acceptable results with free-network bundle adjustment, with an average re-projection error of 0.5 pixels. When using GCPs as described above our check point analysis resulted in RMSEs of 7 cm in planimetry and 6 cm in height. Compared to the pixel size of 5 cm these values are not very good but acceptable.

We used Cyber-City Modeler (Gruen and Wang, 1998) to model buildings on the NUS campus. It is a semi-automatic procedure. While the key roof points are measured manually in stereo mode, the software fits the topology automatically. Giving semi-ordered point clouds measured in a Digital Workstation following a set of criteria, it will automatically generate roof faces and wall faces, where only a small amount of post-editing is needed. It greatly reduces the operation time for constructing building models and can generate thousands of buildings with a fairly small work force. It is also invariant of model resolution, and is able to generate finer details on building roofs such as air-condition boxes, water tanks, etc. We used ERDAS StereoAnalyst as Digital Workstation and implemented a converter between StereoAnalyst and Cyber-City Modeler.

Since Singapore is a tropical country with a large amount of tree canopy around the city, we face difficulties in DTM measurement, especially with images taken at such low altitude of 150 m. Green plants lead to many occlusions. Therefore, for areas where there are trees the DTM resolution cannot be guaranteed. In this scenario, to build an accurate terrain model even under the plant canopy, extra information is needed. We obtained this information by acquiring LiDAR point clouds from a Mobile Mapping System (RIEGL VMX 250), driving around campus. The LiDAR points are used to assist in building a precise terrain model under the trees along the roads and also to derive 3D façade models. For this latter purpose we also have acquired terrestrial images in photogrammetric mode. This is work in progress. Results will be shown elsewhere.

Intermediate results of the building models are shown in Figures 7 b,c,d. This sequence of images shows the development of models from buildings alone, over a combined DTM/building model to a hybrid model including texture from UAV images.



(a) (b)

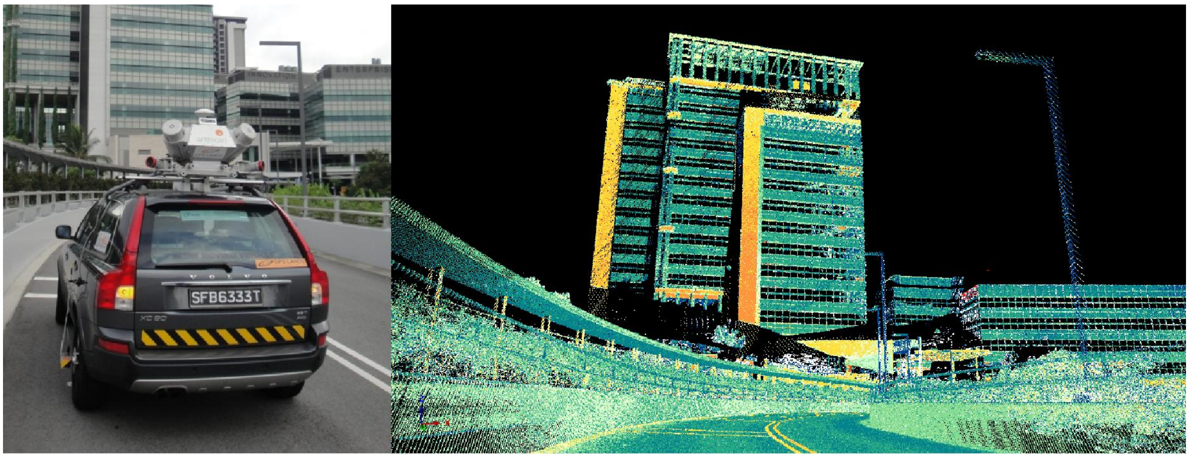
(c) (d)

Figure 7. 3D models of parts of the NUS campus, derived from UAV images. (a) 2 UAV images, (b) geometry model of buildings, (c) buildings and DTM, (d) textured model.

5.2 Acquisition and georeferencing of Mobile Mapping point cloud data

The Mobile Mapping System used is RIEGL WMX-250, which consists of two RIEGL VQ-250 laser scanners, an IMU/GNSS unit, a distance measurement indicator, and two calibrated optical cameras. The system can collect time stamped images and dense point clouds with a measurement rate up to 600K Hz and 200 scan lines per second. Figure 8a shows the system installed on a car. Figure 8b shows a sample of point cloud data of the CREATE area, located at NUS campus "University Town", rendered according to the intensity values.

This project delivered a 16.1 km long trajectory of point clouds and video images. This resulted in 34.4 GB raw point cloud data of road sides, which have been collected within 3 hours, with 5.25 GB sequences of overlapping street images. Due to the mostly bad quality of these images they have not been used.



(a) (b)

Figure 8. (a) Mobile Mapping System and (b) point cloud example data at CREATE building at NUS campus “University Town”

Figure 9 shows the MMS trajectory. The small image blocks represent the intensity values of the Laserscanner.

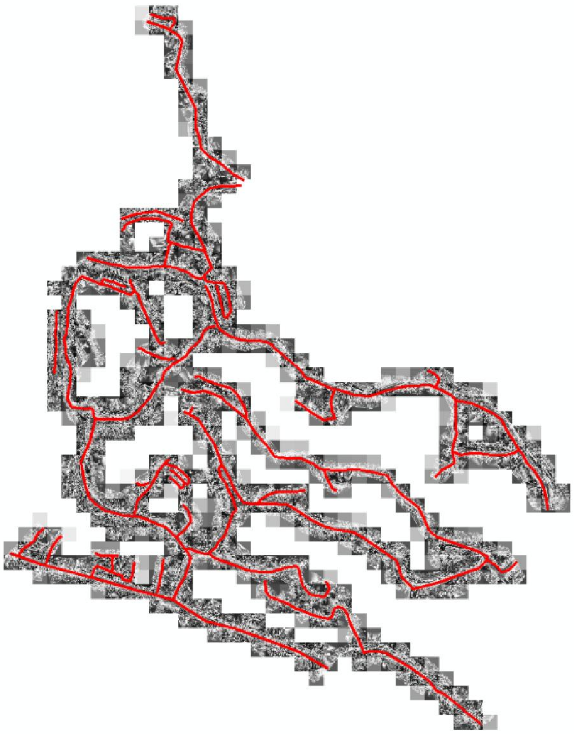


Figure 9. Trajectory of recorded MMS data at NUS campus.

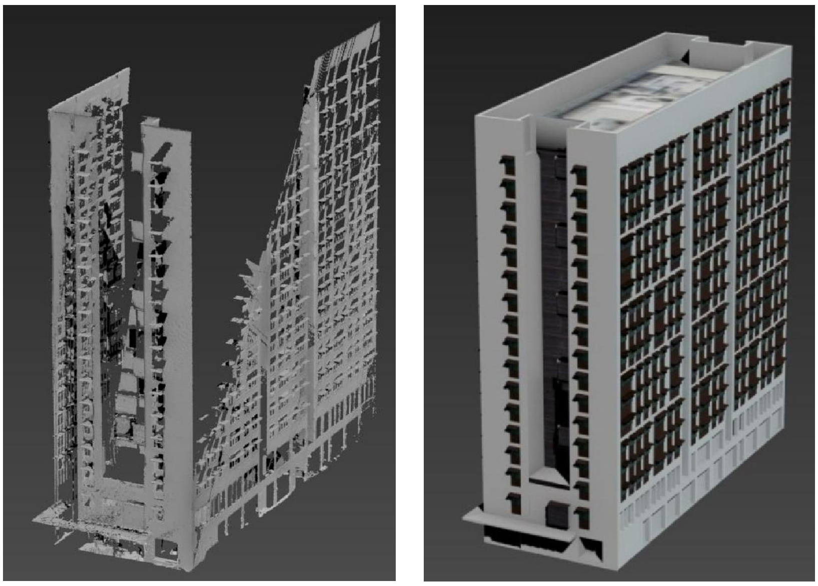
The point clouds have been georeferenced with control points derived from the adjusted UAV image block. Due to many GPS signal losses a great number of control points (169) had to be introduced.
The software used for trajectory adjustments is RiProcess, designed by the RIEGL company for managing, processing analyzing and visualizing data acquired with airborne and terrestrial mobile laser scanning systems. A two-step procedure is applied to adjust the data using well defined control points in the point clouds. The

locations of these control points were chosen regarding criteria like spatial distribution, but also at crossroads, where there were overlapping areas from different passages. In these overlapping areas the fitting is done in two steps, first relative, then absolute to the control points.

A georeferencing accuracy check has been conducted on newly measured check points, rather than on the control points themselves. We manually measured 16 check points from both the UAV stereo images and the point cloud data, evenly distributed over the whole area along the roads. For details of the procedure see Huang et al., 2013.

An accuracy analysis of the georeferencing resulted for the 16 check points the following RMSE values of 11 cm for planimetry and 20 cm for height. These are values which could be expected given the cumulative error budget of UAV images and Laserscan point clouds.

The 3D modeling with point clouds is work in progress. We just present here one building, which was derived from a highly incomplete point cloud, while the texture was taken from terrestrial images. Under the given project conditions high incompleteness of the point cloud is rather the rule. Figure 10a shows the point cloud of the building, while Figure 10b shows the texture mapped building, completed with the 3D roof model derived from UAV images.



a) b)

Figure 10. Result of MMS point cloud data processing. (a) point cloud from MMS, incomplete (roof is missing totally), (b) textured model, including roof structure from UAV images, texture from terrestrial images.

While the 3D façade is derived from the MLS point cloud, the roof geometry and texture comes from the UAV images. Since the MMS point cloud has been registered to the coordinate system of the UAV data, the photogrammetric roof model should fit closely to the façade model.

The manual modeling procedure using 3ds Max works as follows:

(a) Wrap the building point cloud into a mesh model and import it into 3ds Max
(b) Import the photogrammetry roof model into 3ds Max. Both datasets do not match perfectly. The deviation is adjusted manually.
(c) Edit the façade plane to generate the façade features such as windows, balconies and awnings, according to the geometric features in the point cloud mesh model.
(d) For the façade area without point cloud coverage, the façade features can be deduced from the features generated already. Terrestrial or oblique images of the façade can also provide further information for this deduction.
(e) Texture the façade with terrestrial images, which should have been calibrated for good fit (especially the lens distortion should have been removed).

Conclusions

In the first part of this paper we have shown what Geomatics can contribute to the newly evolving smart cities. As an example we have described the functions and products of Geomatics in the context of the SEC-FCL (Singapore-ETH Centre for Global Environmental Sustainability – Future Cities Laboratory) project. A particularly important function is 3D/4D city modeling. We have shown how high-resolution stereo satellite images can be used to derive such models. This followed a fairly standard procedure. Georeferencing with subpixel accuracy was achieved by bias-corrected Rational Polynomial Functions (RPF). The buildings were modeled using CyberCity Modeler and a derivative therefrom. Texture mapping in Punggol was done with an in-house developed software.

In a pilot project the campus of the NUS (National University of Singapore) has been recorded by a Falcon-8 octocopter. This aerial image data has been amended by point cloud data from a Mobile Mapping System and terrestrial images. This results in procedures of fusion on the levels of data processing and of value-added data. At this very high level of resolution (5 cm image footprint) we are facing some serious modeling problems, both from images and point clouds, which cannot be solved by automated routines. Therefore manual and semi-automated modeling still play a key role. This is work in progress. The richness of the data allows many more investigations and products.

Geomatics contributes significantly to the spatial intelligence of modern smart cities. Where does the future take us? It is easy to predict. Those cities that do not change, that do not forge ahead with the use of innovative urban planning, technological and governance models, and intelligent use of resources, those that do not follow the concept of smart cities, will be left behind, with all the negative consequences for their population. They will lose financially, miss the best human talents and suffer economically and environmentally. Yet, in forward-looking and future-oriented cities Geomatics will continue to play an important role in this scenery.

In conclusion, geospatial techniques and Geomatics technologies, in combination with other engineering subjects and social and natural sciences, play an indispensable role in the development of future smart cities. This opens new venues and opportunities for Geomatics, both in terms of R&D and practical applications. It is up to the scientific, development and professional communities to make good use of these opportunities.

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References

Gruen, A., Wang, X., 1998. CC-Modeler: a topology generator for 3-D city models. ISPRS Journal of Photogrammetry and Remote Sensing, 286-295

Huang, X., Gruen, A., Qin, R., Du, T., Fang, W., 2013. Integration of mobile laserscanning data with UAV imagery for very high resolution 3D city modeling. Presented Paper International Symposium on Mobile Mapping Technology, Tainan, Taiwan, May 1-3 (http://conf.ncku.edu.tw/mmt2013/)

Li, D., Shan, J., Shao, Z., Zou, X., Yao, Y., 2013. Geomatics for Smart Cities - concept, key techniques and applications. Geo-Spatial Information Sciences, Taylor&Francis, Vol.16, No.1, March, 13-24

Mueller-Arisona, St., Zhong, Ch., Huang, X., Qin, R., 2013. Increasing detail of 3D models through combined photogrammetric and procedural modeling. Geo-Spatial Information Sciences, Taylor&Francis, Vol.16, No.1, March, 45-53

Pierrot Deseilligny, M. and Clery, I., 2011: APERO, open source bundle adjustment software for automatic calibration and orientation of set of images. Int. Arch. Photogramm. Remote Sens. Spatial Inf. Sci., XXXVIII-5/W16, 269-276

Qin, R., Gruen, A., Huang, X., 2012. UAV Project – building a reality-based 3D model of the NUS (National University of Singapore) campus. Proceedings of the ACRS2012, Pattaya, November 26-30, (http://acrs2012.gistda.or.th/download/)

Schmitt, G., 2012. A planning environment for the design of future cities. In: Mueller-Arisona, S., Aschwanden, G., Halatsch, J., Wonka, P. (Eds.). Digital Urban Modeling and Simulation. Communications in Computer and Information Science, no. 242, Springer-Verlag Berlin-Heidelberg

Wang, T., 2003. Interdisciplinary Urban GIS for Smart Cities: advancements and opportunities. Geo-Spatial Information Sciences, Taylor & Francis, Vol.16, No.1, March, 25-34

Wang, T., Gruen, A., 2012. Georeferencing accuracy analysis of WorldView-02 and IKONOS images of Singapore based on RPFs. Proceedings of the ACRS2012, Pattaya, November 26-30, (http://acrs2012.gistda.or.th/download/)