FROM 2D BASE MAP TO 3D CITY MODEL

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ABSTRACT
Since 1997 Helsinki City Survey Division has proceeded in experimenting and in developing the methods for converting and supplementing current digital 2D base maps in the scale 1:500 to a 3D city model. Actually since 1986 project areas have been produced in 3D for city planning and construction projects, but working with the whole map database started in 1997 because of customer demands and competitive 3D projects. 3D map database needs new data modelling and structures, map update processes need new working orders and the draftsmen need to learn a new profession; the 3D modeller. Laser-scanning and digital photogrammetry have been used in collecting 3D information on the map objects. During the years 1999-2000 laser-scanning experiments covering 45 km² have been carried out utilizing the Swedish TopEye system. Simultaneous digital photography produces material for orto photo mosaics. These have been applied in mapping out dated map features and in vectorizing 3D buildings manually, semi automatically and automatically. In modelling we use TerraScan, TerraPhoto and TerraModeler sw, which are developed in Finland. The 3D city model project is at the same time partially a software development project.

An accuracy and feasibility study was also completed and will be shortly presented. The three scales of 3D models are also presented in this paper. Some new 3D products and some usage of 3D city models in practice will be demonstrated in the actual presentation.

INTRODUCTION
In Helsinki the accurate and continuously updated digital 2D base map covering the whole city area in scale 1:500 has been a basic tool for city planning and building processes as well as for infrastructure and utility maintenance and environmental monitoring. Almost since digital maps and computer systems were introduced and the base map digitizing project in Helsinki started in the 1985, the City Planning Department proceeded into 3D. A 3D model of some parts of the city center was produced by digitizing the original drawings of buildings found in the Archives of Building Regulation Department. Since that first experiment the City Survey Division has produced 3D models for city planners and builders in areal development projects, as ordered
yearly, using the Division’s own photogrammetric workstations. The models have been created using the existing base map as a 2D reference.

A more permanent switching from 2D techniques to 3D techniques seems now (after year 2000) like a “natural” development among the city developers, as new technology is now available. This forces the cartographers to follow their customers and offer the users new three-dimensional data.

When a city is planning to switch from the 2D base map to a 3D city model as its basic part of GI database, many problems must be solved:
- How to produce “old style” 2D maps for official documents and other “old style” users
- How to solve attribute data connections (the base map is part of the city’s GIS and should be connected to the City’s multipurpose cadastre)
- Is the quality of current data sufficient for 3D
- Is there enough height information
- How the abilities of 2D draftsmen bend to 3D operations
- What is a suitable and effective data model and classification of the map database
- How the software in use handles 3D objects, what new tools are needed
- How the 3D updating is to be organised
- Etc…

THE 3D PROJECT

The Helsinki City Survey Division started an internal project to convert the base map 1:500 into a tree-dimensional database in the autumn of 1997. For four years there has been experimentation, research and planning in order to transfer into a 3D base map, a virtual 3D model of the city.

Currently all new field surveys and stereo photogrammetry updates come in 3D and are already saved according to their real heights. The file format has been changed into a 3D file format. The information of the heights (contour lines and spot height points) is located already at the correct height in the 3D file. All the other data though, is still at ground zero (height value = 0 meter). The conversion of the entire map database must be done. Indeed, the map database is in hybrid state, heights and newly mapped objects are in 3D, old data is in 2D.

MORE DATA ON HEIGHTS OF THE TERRAIN AND OBJECTS IS NEEDED

Due to experiments and resolving, the fact has been made clear that the height information in the current 1:500 maps is not adequate to create a visually sufficient, precise model of a city. Significantly more information of heights must be acquired. Actually, height observations must be made for every square meter area of the city, which in Helsinki would mean a total of 186 million height observations for an area of 186 km². In the current map there are extensive regions (yards and streets) without contour lines. To gain this information is imperative in order to create an accurate model. In the regions with contour lines, the need is not so apparent, but there the information could be checked, and the quality of the heights will be generally amended.
THREE SCALES OF 3D MODEL

City models are needed in different scales or modes for different functions, just as currently the base map 1:500, the office map (1:4000), the tourist map (1:10000) and the region map (1:40000) are in use in the present day map system. In the city model work under discussion first solutions have been composed to fit the levels of precise work and overall observation. These may account to the conventional scales from 1:200 and 1: 5000, comprising in city planning terms from detail planning to general planning needs. More general models have not been thought out yet.

Conclusion has come to three models:
1. The rough city model
2. The precise city model
3. The textured precise city model

With experimentation it has been concluded that it is possible to produce a rough city model based on the current base map data and the levels information on buildings in multipurpose cadastre database. In this model, a terrain model is created from the current height information in the base map and an ortho photo (an ortho rectified aerial photograph) is dropped on the model. According to the number of floors, the buildings are lifted to the approximately correct height as cubes, and further on dropped to the surface of the model. Standing crop has not been modelled. The accuracy of the model in xy directions is the same as in the base map (~5-10 cm). However in the z direction it is some meters in house heights and ~ 0,5-1 meters in terrain features.

Picture 1: A rough model of Länsi-Pasila.
The 3D expression or equivalent of the base map is a **precise city model**. In that model every element of the map has been fitted to its correct height and the break lines (break lines = the edges of streets and sidewalks, fields etc. planar objects) have been defined. The roofs of buildings have been saved after they have been measured into their correct forms. Standing crop has not been modelled.

The accuracy of the model is in xy directions same as in the base map (5-10 cm), but in z direction some 15 cm in house heights and some 5-15 cm in terrain features.

The **textured, precise city model** can be produced from a project region by adding texture to the buildings and modelling the standing crop and other 3D features. At the city-centre texturing has been made with the use of façade photographs. Also in this product an ortho photo can be used to better describe terrain features. The production process has been used in the city planning departments Kamppi-Töölölähti bay area models and other projects.

**Picture 2: A textured, precise model from Rautatientori.**

**NEW TOOLS, NEW SKILLS, NEW OCCUPATIONS**

As the shift from the digitally maintained 2D base map to the 3D city model is approaching, it affects considerably the city survey organization responsible for the city base map: the processes, tools, map database, map system and the personnel. The transition to 3D modelling makes demands for the improvement of the personnel; in a way it is a question of learning a new profession. Old software needs to be improved, and there will be a need to partially shift to completely new products in map database conversion and update. In regard to the maintenance of the base map, new 3D attributes are being developed to the Stella-products, the current software in use in Helsinki (Finnish application over Bentley’s MicroStation). The Terra-products in use, TerraModeler, TerraScan and TerraPhoto are undergoing a period of intense progress. 3D project has partially been a software tools development project with tight connections between the modellers in the city organisation and the software developers. The format of the base map database will partially change and a new part of the base map database will be a terrain model based on spot height points and break lines.
Work procedures for conversion of 2D features and guidelines to use new tools have been developed during the test project period. The methodology for continuous updating the 3D map database is under construction.

MORE HEIGHT INFORMATION VIA LASER-SCANNING

Gathering the height information is a big project. It needs new methods and tools, and, if possible, automation. Height modelling by an operator using stereo photogrammetric work or interpreting laser scanned points (ground level, buildings, and the edges of street elements as "break lines") would take 15-25 man years of work according to the calculations of our experimental projects. In Helsinki, the possibility of using laser-scanning as a method to gather information has been experimented by making two test projects (40 km²) from the area of the city centre and a part of eastern Helsinki. The first mission was accomplished in late 1999 and the second in autumn 2000. The laser-scanning consultant was Swedish TopEye Ab.

*Picture 3: A cross-section of laser-scanning points from Pohjoinen Rautatiekatu.*
Picture 4: A classified point cloud from at the Swedish Theatre.

Picture 5: The Swedish Theatre vectored out from the scanned point cloud.
A xyz-observation has been obtained from almost every m\(^2\), the scanned 40 million points have been classified into ground, tree, and building points. A terrain model can be constructed from the ground points. Accuracy would seem to be \(~5\text{-}20\text{cm}\) in every direction. Preliminary research concerning accuracy has been prepared, and is showing these results.

Laser scanned point clouds are stochastic in comparison to points achieved by stereo mapping method (where few points are targeted and measured). During scanning the observation points hit randomly some spots in the terrain (sometimes in human beings, traffic signs etc.). To understand this, and to adapt it in modelling a city may take some time to learn.

**SMALL DIGITAL CAMERA USAGE AT LASER-SCANNING: PRODUCING ORTHO PHOTO MOSAIC**

During the second laser-scanning mission in 2000 also digitalortho photo mosaic production was added to the production system.

Digital photographs taken with a small camera simultaneously with the laser-scanning have been semi-automatically, without measurements, prepared into a ortho photo mosaic.

*Picture 6: An ortho photo and the base map.*
The location error on top of the base map seems to be at maximum about 10-15 cm and apparently sometimes happens at the joints of the individual pictures. The pixel size of the ortho picture mosaic is about 5cm. The location accuracy can be improved by pointing out common points from the pictures, but at this time there was not possible to do this since there was about 12500 pictures from the eastern area.

This small picture ortho photo mosaic is by itself an interesting product, and the possibilities of its use are researched. It is also a medium that helps the modeller to model streets and the roofs of buildings; the operator modelling the area by laser scanned points can view the area under work far better. There are still some problems with this small picture mosaic; because of the small flight height of the helicopter (200 m) and few overlapping of the pictures, high houses are seen sideways and their roofs can not be well modelled (TerraPhoto software developer is working on the question towards true ortho pictures).

A 3D model of the whole city

Laser-scanning the rest of the city is being thought over. Before it, the full ways of use in determining "break lines" and constructing roofs from the pictures and points of the 30km
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 scanned at the end of the year 2000 must be taken into account. The exploitation of the other parts of the scanning data seems clearer. It is somewhat a question of the observation data growing old; it is folly to gather expensive data to hold in store when the terrain changes. In other words: laser-scanning methods must be a part of the normal work procedure of the surveying division before more scanning can be accomplished. According to the project’s findings laser-scanning data can be used in further 3D modelling of the city and in the conversion of the current 2D base map to 3D. It seems to be the most effective way, if only the work procedures and personnel can be adapted to new methods. New automatic or semi-automatic tools have just developed for “lifting” street element edges and for vectorizing the roofs of buildings. How effective those new tools are, will become clear during the next months. Some hopes exist, that we can decrease the estimated conversion time consumption by 50%. If this can be done, then the Helsinki City Survey Division will continue with laser-scanning projects over the rest of the city area.

The more traditional stereo mapping from aerial photographs will still be contributed to. Another digital stereo workstation has been obtained to the city survey division last year. We still continue to take aerial photos in scale 1:3000 covering one third of the city each year for map updating purposes. The yearly cost of the air photos of 70 km
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, paid to a consultant company, is about 25000-30000 €. From them division gets film pictures ready for scanning. Some 2-3 km
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 of the photos are then yearly used in mapping at stereo workstations to update the base map. The rests of the photos are kept in reserve. The map updating process currently relies on the products of the stereo workstations.

In comparison: making a laser-scanning mission of a third of the city area (70 km
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) may cost some 120000 € paid to a consultant company, from whom a raw laser point cloud (some 70 million points) and some 20000 raw digital photos (maybe 400 GB) are obtained. After a few months work classified points (ground, trees, buildings) and small camera ortho photo mosaic covering the whole area can be extracted and prepared from raw data. The ground point data is directly useful as a DEM (Digital Elevation Model) and the ortho photos may be useful for map updates and other purposes.
Checking the street areas of the base map and standardizing the data is currently underway in the graphic element of the street database of the Public Works Department. The different areas of the street (drive way, sidewalk, green strips, traffic islands etc.) are saved as 2D areas. This checking has shown itself to be unavoidable also as a phase preceding the creation of the 3D edges, "break lines" of the streets. The old base map is, even if all features nowadays have a feature code, partially “spaghetti data” and there are some digitizing errors, which must be removed before the lifting of those elements to the right height level on the 3D model is possible. A new problem occurred during this work phase: MicroStation could not handle correctly “bumpy” (irregular) surfaces as areas in 3D mode. We were forced to drop the street elements back to lines and other graphic primitives in 3D model.

Lifting the old 2D map data from 0-height level "map sheet by map sheet" to the correct height is possible after the break lines (or edges) have been figured out. The first, experimental map sheets will be attempted to figure out within this year. In constructing a precise model the drawing up of break lines and constructing the buildings are the largest job. There, if anywhere, the biggest benefits of using automatic tools in 3D modelling will be gained.

**2D GIS map and 3D city model**

At the same time the GIS development needs for the base map database are different from the 3D city model development demands:

- Area features where the attributes are to be connected for real estates, buildings, “city plan units” as areas.
- Specific demands for map features from different city departmental GI Systems like the street administration register need 2D areas (drive way, sidewalk, green strips, traffic islands, etc.)

It is a special job to coordinate different demands, proposals and project and keep the base map database updated and useful for the entire city administration, all citizens and other map users. This effects the 3D model development.

**Problems to be tackled**

There are incomplete questions yet to be resolved before systematic conversion will begin:

- Securing the consistency of 2D GIS map database and 3D City model and the production processes of old 2D map products from 3D model.
- Finalizing the structure of the 3D model database (3D base map) and the instructions for map feature catalogue and mapping processes of the features.
- Finalizing the height description and recording methods in the base map database and in the current 2D base map 1:500 print out product.
- Automatic tools to model roofs (this seems to be solved at the time as this is being written).
- Automatic ways to model the standing crop and forests.
- Starting the systematic production conversion of 2D base map to 3D city model

**Development of Laser-scanning and Multi Sensor 3D data collection**
These technologies are under vast development and some expected and needed enhancements are:

- More laser points per second (currently 7000).
- More digital pictures per second and with 4-6 cameras, where two are aimed to sides (30 degrees) and two main cameras partially overlapping down, one front and one back, all partially (20%) overlapping.
- Automatic software tools to use the data to create and update city 3D city model.
- Database development to store aerial photos with their picture cones (photogrammetric orientation parameters and middle and corner vectors), which are nowadays available via GPS and Inertia equipment used in the helicopter during the laser-scanning mission.
- Infra-red camera(s) should be permanently included (to find the heat leaks in heat pipes and buildings)

**CONCLUSION**

There are still some obstacles on the way to a comprehensive and continuously updated 3D city model functioning as the base map of the City Helsinki. Work in order to reach this goal is under way and we may see the results in the next 2-3 years.

**REFERENCES**


CV OF THE AUTHOR

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