

# IMPROVED 3D CITY MODELING WITH CYBERCITY-MODELER (CC-MODELER™) USING AERIAL-, SATELLITE IMAGERY AND LASERSCANNER DATA

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## ABSTRACT:

Semi-automated object extraction has been established as a standard procedure for the efficient generation of 3D city models. Apart from aerial imagery, satellite imagery and laserscanner data turned out to be an additional source to create virtual city models. CyberCity-Modeler (CC-Modeler™) as a tool for the generation and optimisation of 3D city and plant models has been used in a range of projects with different requirements. Therefore modules have been developed and integrated to the main software package to improve functionality. CC-Modeler™ consists of four modules: CC-Modeler for topological structuring, CC-Edit for improving geometry, CC-Mapping for integration of wall texture and CC-Digit for integration of digitised data from maps. Concerning the software package CC-Modeler™, some functions as geometrical regularisation of buildings, editing functions for topology adjustment, modeling of overhanging roofs, adding attributes to objects, mapping from texture libraries, generation of corridors etc. are explained in this paper. Additionally, the use of satellite and laserscanner data for the efficient generation of 3D city models as an alternative or supplement to aerial images is discussed and the progress in real-time visualisation of 3D city models is presented.

## 1 INTRODUCTION

CyberCity-Modeler (CC-Modeler™) uses semi-automated object extraction from stereo-models of aerial and satellite imagery towards the generation of realistic 3D building models. Additionally, all objects which can be represented as polyhedral models like digital terrain models (DTM), roads, waterways, trees etc. can be modeled. The automatic detection of main roof types from laserscanner data is under development.

CC-Modeler™ is a commercial software product that is marketed by the ETH Zurich spin-off company CyberCity AG. Realistic 3D city models are used primarily in city-, facility planning but also in location planning of telecom companies, 3D car navigation systems, scene modeling in game industry etc. Due to variability of applications, the software is improved ongoing with the different project specifications and is adapted to specific needs and requirements.

This paper discusses data capturing of point clouds from a stereo-model for further processing with CC-Modeler™. In addition, the four modules of the CC-Modeler™ are presented and the workflow to improve the 3D building model is pointed out. Furthermore, functions like generation of overhanging roofs, adding basements and attributes are explained. Results (incl. accuracy) from different data sources like aerial and satellite imagery and laserscanner data are discussed. Eventually, latest progress in real-time visualisation of 3D city models is presented.

## 2 DATA CAPTURING FOR 3D CITY MODELING WITH CC-MODELER™

Photogrammetry assists in derivation of information on surface cover (e.g. vegetation) and man-made objects (e.g. buildings, roads, bridges etc.). CC-Modeler™ enables generation of 3D building models from aerial images with use of a semi-

automated method. This topology generator fits planar structures to point clouds that are measured by a human operator. The photogrammetric measurement and structuring is done on Analytical Plotters or on Digital Photogrammetric Workstations (e.g. Virtuozo, Socet Set, Z/I Image-station etc.). The operator classifies the captured points in boundary points and interior points, based on their different functionality in one object (Figure 1). Different codes are assigned to these points, which help the CC-Modeler to generate the roof faces and an accurate topology. Each roof type can be generated and there are no constraints regarding a roof type library.

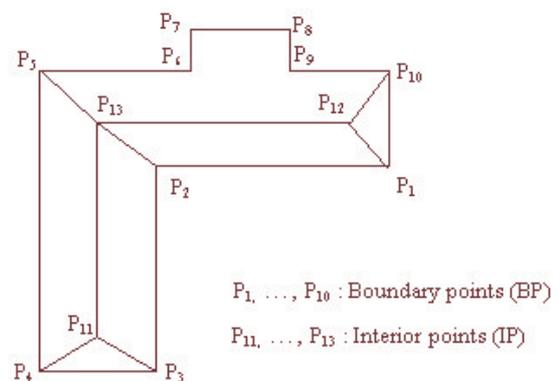


Figure 1. Point definition in CC-Modeler.

The points of the roof boundary polygon have to be measured clockwise or counter-clockwise (in case of the interior points, no sequence has to be kept). The interpretation of the data depends on the operator which gives the opportunity to achieve any level of detail. With this method, hundreds of objects (i.e. buildings, roads, bridges etc.) can be measured by one operator in one day.

### 3 CYBERCITY-MODELER (CC-MODELER™)

Originally, CyberCity-Modeler (CC-Modeler™) was a research project at the ETH Zurich and was later implemented as a commercial product from the CyberCity AG (Gruen, Wang 1998). It was designed for data acquisition and structuring for 3D city model generation. Besides structuring, the integration of real image texture should be possible and assigning attributes to objects should be permitted.

To fulfil project constraints, the functionality of CC-Modeler™ was extended and now consists of four modules:

- CC-Modeler for topological structuring and extraction of realistic roof and terrain texture from aerial images
- CC-Edit for improving the geometry of the building model and adding attributes or basement
- CC-Mapping for integration of wall texture
- CC-Digit for integration of digitised data from maps.

Figure 2 shows the work- and dataflow in the CC-Modeler™. The point clouds that are measured on an Analytical Plotter or on a Digital Station or taken from maps with CC-Digit, are structured to roof faces in CC-Modeler. The data is managed in the own V3D-format and can be edited with CC-Edit. Data export to formats of major CAD systems (e.g. DXF, DGN etc.) and visualisation software (e.g. FLT, VT etc.) is provided.

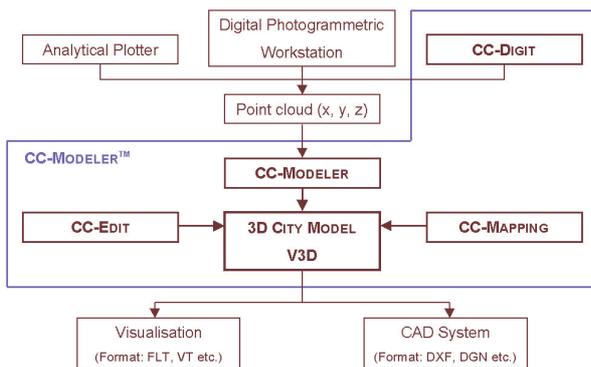


Figure 2. Dataflow CC-Modeler™.

#### 3.1 CC-Modeler

As a topology generator, the CC-Modeler, which is the basis module, generates roof topology from manually measured point clouds. This workflow can be automatic or in step mode for detecting face mistakes that can occur due to inadequate point measurement.

A few main editing functions in 2D or 3D view enables solving these problems. In the 2D view, the vector data of the 3D objects (roof polygon) are projected on the original aerial image or orthophoto to check how the measured data fit to the ground (Figure 3). Through this projection, the DTM and the roofs can be textured automatically from the aerial image.

To generate vertical walls, the roof border polygon is projected on the DTM and intersected with it.

With this first implementation of the CyberCity-Modeler software package, it is even possible to texture building facades with realistic images.

With this main module, the internal data-management structure can be translated into different formats readable by AutoCAD, Microstation, Polytrim, ArcView and Iventor (i.e. DXF, DWG, DGN, IV, AutoLisp etc.). Converter to visualisation formats like FLT (Open Flight) and VT (VTree) are available.

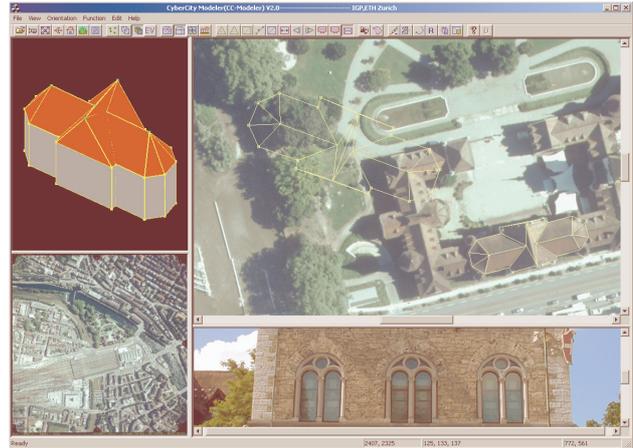


Figure 3. Graphical User Interface of CC-Modeler.

#### 3.2 CC-Edit

Developed as a research project, the commercial implementation of CyberCity-Modeler has to fulfil some specific practical requirements in an efficient way, that led to modifications and additions in the basic software package. CC-Edit as one of these additions was developed as a CAD system for 3D city models targeted to the V3D structure.

With different editing functions, the measured objects, that are as close as possible to their existing size and shape, can be regularised in geometry (Paragraph 3.2.1). For the realistic modeling of the building facades, an additional function is integrated to create walls and overhanging roofs with the use of cadastral maps (Paragraph 3.2.2). Even basements with arbitrary depths can be added to buildings (Paragraph 3.2.3). The V3D-structure allows to save information about buildings as attributes and some geometric attributes (e.g. volume, area etc.) can be calculated automatically (Paragraph 3.2.4).

New extensions are implemented during new project work which improve the software and make it flexible and successful.

##### 3.2.1 Workflow to improve geometry of 3D city models

The next paragraph is devoted to the workflow of achieving best data quality for further processing, because in measurement, some errors can occur by the limits of interpretation. This may lead to edge or ridge lines that are not parallel or roof faces that are not planar.

CC-Edit uses two strategies: automatic adjustment based on least squares (Gruen, Wang 2001) and an approach of CAD editing. The aim of the editing process is the generation of a 3D model that meets the following conditions:

- Same height for groups of eaves points and ridge points.
- Roof faces with more than 3 points should be planar.
- Collinearity of eaves and ridge lines.
- Right angles in main structures.

##### 3.2.1.1 Face adjustment and height processing

A number of query functions facilitate the detection of differences in the model geometry. It is possible to check the height of the two end points in a selected line that can be for example the eaves or ridge line. To improve the quality of the building, one can change the height of a selected point manually or set the two points to an average height or to the height of a selected base point.

This same height processing can also be done automatically for the whole model with an additional face adjustment. For each

ridge and eaves line, the average height is calculated if the difference of the z-coordinate of the points is less than a threshold in meters (default value in the parameter settings is 0.25 meters).

With another query it is possible to check, if the faces of a model are coplanar. The maximum of the difference between the face and the points is displayed and the points deviate from the face are marked with a red rectangle, which leads the operator to the parts of the model that have to be further edited (tolerance is parameterised).

### 3.2.1.2 Grid functions

To get high quality buildings that may be combined with cadastral data, some additional improvements are required (e.g. orthogonality of the outline).

In case of a simple geometry, this process can be accomplished automatically for one building or a group of buildings.

For the alignment of complex structured objects, a grid can be set as a reference system, either automatically or manually. The grid that consists of parallel construction lines is overlaid to the lines that connect the measured points. The concerned object points are snapped to the appropriate grid points which adjust the object lines automatically to the direction of the grid lines. The snapping box size parameter can be set according to the different accuracy requirements.

Orthogonality, collinearity and the planar face constraint are taken in consideration by using this editing process (Figure 4).

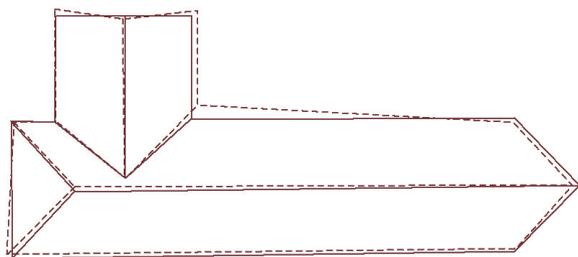


Figure 4. Object rectification (dashed line: before, solid line: after).

### 3.2.1.3 Point fitting

There are different possibilities to fit measured points to a fixed structure. A number of selected points can be fitted to one line. In case of a wall that is described by a curve, the points along the wall can be fitted to a symmetrical curve. Cylindric objects are difficult to measure in aerial images. The border polygon of these objects can be fitted to a circle, where the number of circle points can be set in the input parameters providing thus different accuracy.

If it is necessary for the improvement of the model, new points can be added to the roof polygon and later fitted with the former mentioned methods.

### 3.2.1.4 Topology adjustment

Inconsistencies in topology between adjacent buildings and mutually overlapping roofs may arise because of measurement errors. They can even exist after the previous explained editing on the 3D model to improve geometry. To solve this problem, CC-Edit offers an automated and a semi-automated procedure.

In the automated mode, the system selects a reference border line which is kept fixed and onto which the points of the other lines are projected perpendicularly. As reference line, the longest line is selected, because it is assumed to be the most

stable line (Figure 5). In the semi-automated mode, this reference line is selected manually.

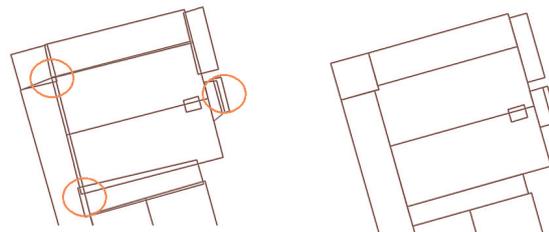


Figure 5. Topology adjustment. Left: original, Right: automatically corrected with CC-Edit.

### 3.2.1.5 Roof superstructures

Roof superstructures for example windows or chimneys are measured and managed separately. Without editing work, these structures have walls from the roof to the ground surface after the intersection of the roof points with the DTM. With CC-Edit it is possible, to combine the main building with his superstructures and cut the walls of the small objects on the roof face in the way, that after editing, in the main building no further senseless walls exist. Thus all objects are characterised as standalone objects.

After intersecting, the base point of a superstructure is included in a face of the main building. While editing the roof, this condition can be lost, but with a simple function, the concerned point can be moved into a chosen direction until it fits to the face again.

### 3.2.2 Generating walls and overhanging roofs from cadastral maps

In general, facades are not visible in aerial images and only the roof surfaces can be measured. Digital cadastral maps, which show the outer walls of buildings as part of the legal definition of real estate property, can be used to integrate realistic facades. Utilising this information, it is possible to model overhanging roofs and get a higher level of detail in building modeling (Figure 6).

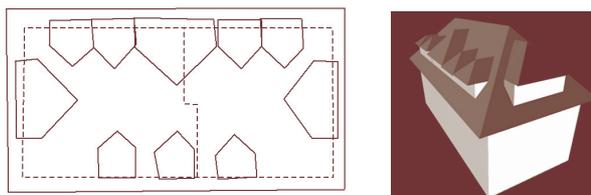


Figure 6. Automated facade integration. Left: Roof polygon and facade from map, Right: Overhanging roofs as result.

This procedure is not easy to automate. Sometimes, the roof border polygon is not concordant with the facade border line (Figure 7). This can occur if the facade appears shifted or rotated relative to the roof due to measurement errors or in case of outdated maps. Additionally it has to be mentioned, that maps may show a lot of peripheral details like stairs which make this procedure be handled by an operator.

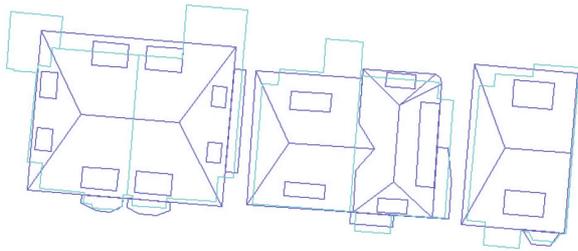


Figure 7. Roof polygons (dark) and facade representation from maps (light).

### 3.2.3 Basements

As a new function, CC-Edit allows to add basements to one house or a group of houses. The depth of the basement can be set individually. These information can be used for geometric calculations as described in the following paragraph on attributes.

### 3.2.4 Attributes

Information about the objects can be saved as attributes. With the attributes query & edit dialog these information can be enquired and modified. A number of objects can be combined to a complex object for saving the same attributes.

CC-Edit allows to calculate geometric information for planning purposes. At that moment the following geometric attributes are implemented (other calculations can be implemented on request):

- Height (of eaves line)
- Upboard area (area of eaves)
- Ground lowest/highest height
- Basement-lowest height
- Base-map area
- Volume

Solutions for the management of 3D city models in a spatial information system are proposed (Gruen, Wang 1999; Wang, Gruen 2000). An implementation of this idea in a commercial GIS is in progress.

## 3.3 CC-Mapping

The module CC-Mapping was developed for fast texturing of the walls and roofs of the 3D city models in our format V3D. Recently, a tool has been developed, that uses the textured image to create corridors through a building part.

### 3.3.1 Wall/Roof Texturing

The roofs can be automatically textured with realistic texture from the aerial images with CC-Modeler or can be mapped with colour in CC-Mapping, as same for the walls (Figure 8).

Most realistic textured models can be get through wall pictures that are taken on site with a digital camera. Obstacles like trees, cars or people and the perspective view of the camera makes image processing necessary. After mapping an image, a link to the corresponding image is created in the V3D file, comparable to the VRML format.

For generic texturing, a library of texture images can be used. With minimum effort, the walls of a model can be textured with sample images, that best fits to the environment of the model, when realistic textures are not required. The sample images represent only a part of a specific wall type. For texturing, this part has to be repeated correctly on the wall.

The implementation of a random distribution of generic textures to the whole model is in progress.

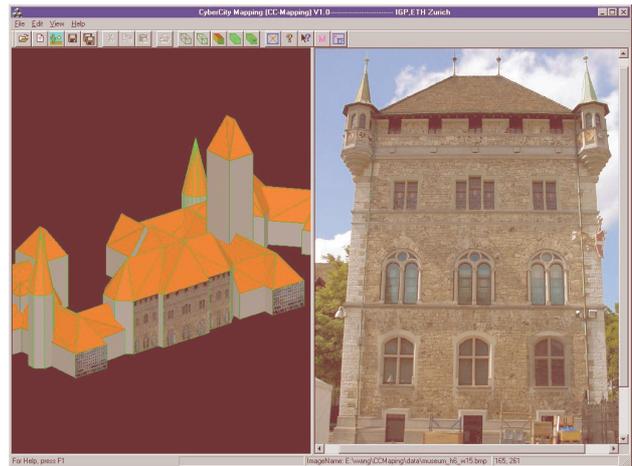


Figure 8. Graphical User Interface of CC-Mapping.

### 3.3.2 Corridors

This function uses the fact, that a corridor looks most realistic, when it is created exactly according to the facade image, where the walkthrough is visible. In CC-Mapping the model including the facade images is loaded and displayed. If the wall, where the corridor should be created, is selected, the image appears on the right window of the software and the border of the walkthrough can be digitised and is generated automatically by the software (Figure 9). Thus, arcades can be generated with minimum effort.

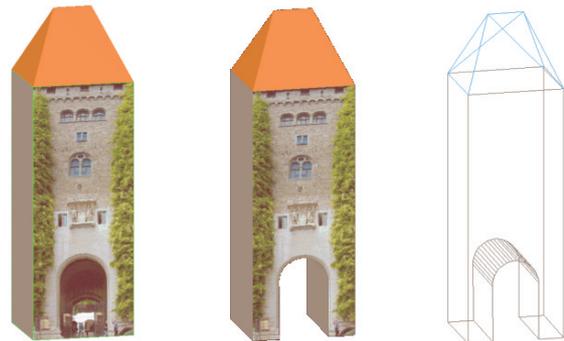


Figure 9. Corridors. Left: Original textured model, Center: Generated corridor, Right: Corridor in wireframe mode.

## 3.4 CC-Digit

For planning purposes, it is important to be able to create 3D models of future buildings on the basis of maps and architectural schemes because they cannot be measured in the actual aerial image.

With CC-Digit, the border polygon of the planned buildings can be captured easily by digitising the border points. This module creates the same file format like the data capturing system with an analytical plotter or a digital station which can be handled by CC-Modeler and be converted to different formats like VRML or the internal format V3D.

This module provides the fast generation of buildings that have to be visualised in a planning process.

#### 4 DATA SOURCE

Aerial, satellite imagery and laserscanner data are used as raw data (see paragraph 2) whereas depending on requirements, different approaches are applied.

##### 4.1 Aerial imagery

At that moment, aerial images are the most common used raw data (Figure 10). For capturing the 3D point cloud for further processing in CC-Modeler™, the stereo pairs of the images are needed. The scale of the images depends on the accuracy that is required for the 3D model and is normally about 1:5000 with a forward and a side overlap of 30 and 60 percent respectively. If the images are used for True-Orthophoto, the side overlap is suggested to be 60 percent.

Using this data, many building details can be measured from the aerial images and the measurement error is maximal 0,2 meter in height.



Figure 10. 3D city model Karlsruhe (derived from aerial imagery). Courtesy of Vermessungsamt Karlsruhe.

##### 4.2 Satellite imagery

In case of large areas, recently high resolution satellite imagery is used, like the 1-meter panchromatic from Ikonos (Figure 11). The data capturing process is the same as with aerial images, but the accuracy is less, measurement error can be up to 1 meter in height. DTM and Orthophoto can be derived automatically.

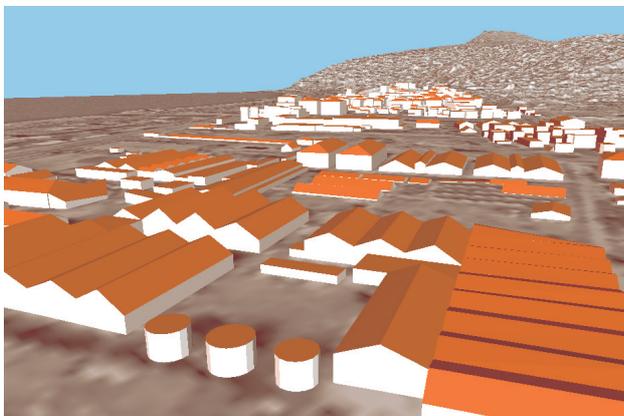


Figure 11. 3D city model Izmir (derived from satellite imagery Ikonos).

##### 4.3 Laserscanner data

For the generation of 3D city models from laserscanner data, a density of laserscanner points of more than 2 points/sqm are required. Big areas are already surveyed with laserscanner, which is seen as an advantage for the application of this data.

The procedure for the calculation of 3D building models from laserscanner data uses a tangential plane as a first approximation that suits the laserscanner points. From this geometric model, edge lines are derived whereas edge lines of building structures are generated (e.g. eaves lines, ridge lines etc.). These lines are combined to faces to represent the roof planes. It is possible to automatically derive standard roof types like saddleback roofs or pavilion roofs (Steidler et al. 2002). This part is still under development (see example in Figure 12). The accuracy is expected to be 0.3-0.5 meters in height.

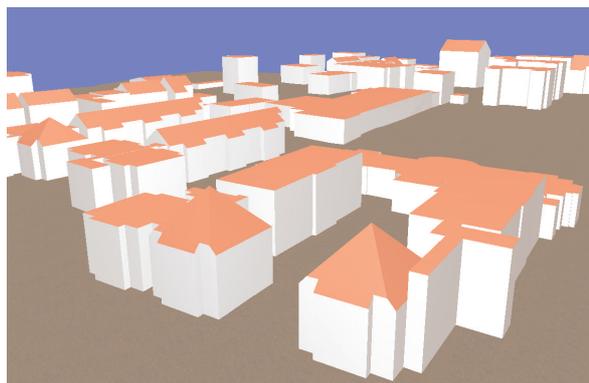


Figure 12. 3D city model (derived from laserscanner data).

#### 5 REAL-TIME VISUALISATION

Visualisation is performed by real-time tools like TerrainView ([www.viewtec.ch](http://www.viewtec.ch)) or CyberWalk ([www.muellersystec.de](http://www.muellersystec.de)). TerrainView and CyberWalk are two competitive products with interactive user interfaces. In particular, they are able to display terrain and buildings as separate objects. Free navigation within a selected geographic area are allowed. Foreground and background are displayed with different data subsets which means that a level-of-detail (LOD) is provided and performance and storage capacity is optimised. Data is compressed and decompressed during visualisation. Features like flight paths, weather simulation etc. can be provided.

For high quality visualisation, the use of a True-Orthophoto is recommended to avoid that the roof texture is visible on the ground beside the building.

In the meantime, even the real-time visualisation of the interior of buildings is possible (Figure 13).



Figure 13. Interior of a church visualised with CyberWalk.

## 6 CONCLUSIONS

CC-Modeler™ is a tool that uses a semi-automated object extraction from photogrammetric stereo models to generate realistic 3D building models. It is independent from the photogrammetric data capturing system and with the module CC-Edit a powerful tool to modify and improve the geometry of 3D models is provided.

The possibility of the integration of cadastral maps for the generation of overhanging roofs, the mapping options and the option to generate corridors from facade images makes 3D city models more realistic.

Hence CC-Modeler™ is a unique tool for generating 3D city models efficiently and with a high degree of detail and accuracy and the option of attribution means a next step to a three-dimensional GIS.

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