# Cities from the sky

## Photogrammetric modeling of CyberCity is coming of age

**Journal Article**

**Author(s):**
Grün, Armin

**Publication date:**
2001-12

**Permanent link:**
https://doi.org/https://doi.org/10.3929/ethz-a-005717580



**Originally published in:**
Geoinformatics 4(10)

# Cities from the Sky

## Photogrammetric Modeling of CyberCity is Coming of Age

**The recent terror attack on the twin towers of the World Trade Center and the Pentagon has shown in a drastic manner the vulnerability of our open societies. 3D city models and their unrestricted access are a typical product of the modern information and communication age. Like any other high tech product, these models may serve good and evil purposes at the same time. They can be used to simulate critical situations and to find measures for protection and also, if an incident has happened, to optimize the rescue activities. But, on the other hand, they may be used by terrorists and other criminals for the preparation of their activities. It is the responsibility of all of us to produce and use these 3D city models for the benefit of mankind and to help in the search for measures to avoid acts of terrorism and vandalism.**

By Armin Gruen



It is only over the last 12 years that photogrammetric approaches to building extraction and modeling have evolved. What started out as a pure research issue has now found firm grounds in professional practice. After the first phase of efforts to extract buildings fully automatically the tight specifications of users have led to the development of efficient manual and semi-automated procedures. Actually, the need to extend modeling from simple to much more complex buildings and full ensembles and to even generate complete city models (including DTM, roads, bridges, parking lots, pedestrian walkways, traffic elements, waterways, vegetation objects, etc.) puts fully automated methods even further back in the waiting line of technologies for practical use. In a sense the user requirements have outpaced the capabilities and performance of automated methods. However, to make it clear, automation in object extraction from images is still and will continue to be a key research topic. In the meantime aerial laserscanning is attracting much

*As always with new technology, expectations are exaggerated.*

attention. As always with new technology, expectations are exaggerated. This is not the place to discuss the problems of this technology, but it can safely be stated that it is not yet ready for high resolution city modeling. There are many fully automated approaches to building extraction, but only very few that were designed as semi-automated ones from the very beginning. Very often, procedures are declared as automatic but require so much post-editing that their status as automatic methods becomes questionable.

*Fig 1: Modeling of a chemical plant (combination of vector and raster image data). (Courtesy CyberCity AG, Bellikon, Switzerland).*

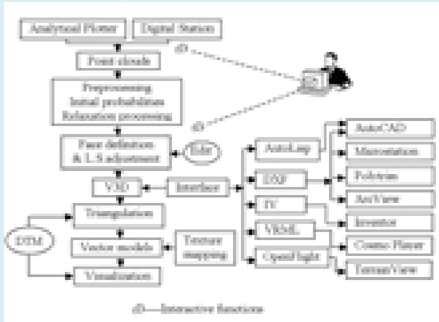



*Fig.2: Data flow of CC-Modeler.*

### Applications

Applications of city models are manifold. Currently the major users in Europe are in city planning, facility mapping (especially chemical plants and car manufacturers, see Figure 1), telecommunication, construction of sports facilities and other infrastructure buildings. Others include environmental studies and simulations, location-based services (LBS), risk transports and analysis, car navigation, simulated training (airplanes, trains, trams, etc.), energy providers (placement of solar panels), real estate business, virtual tourism and micro-climate studies. Interesting markets are expected to develop in the entertainment and infotainment industry, e.g. for video games, movies for TV and cinema, news broadcasting, sports events, animations for traffic and crowd behaviour, and many more.

### Techniques for Data Generation

Diverse applications require different levels of detail in modeling, a great variety of different objects to be extracted and the handling of different data types and manipulation functions. Therefore, when designing an efficient method for object extraction and modeling the following requirements should be observed:

- Extract not only buildings, but other objects as well
- Generate truly 3D geometry and, if a GIS platform is being used, topology as well
- Integrate natural image texture (for DTM, roofs, facades, and special objects)
- Allow for object attributation
- Keep level of detail flexible
- Allow for a wide spectrum of accuracy

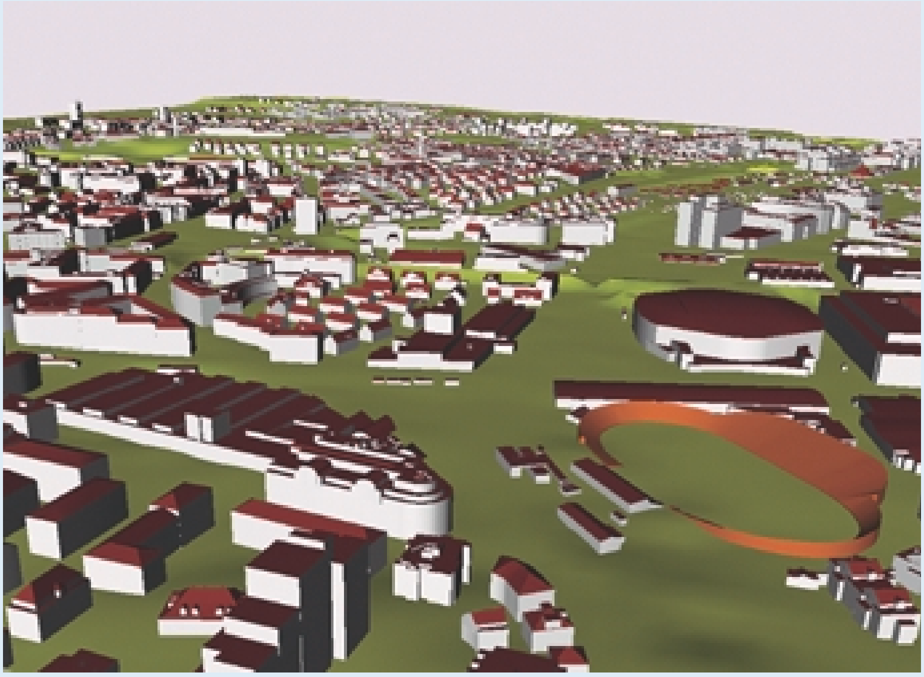


Fig.3: City model Zürich Oerlikon. Note the modeling of non-planar surface objects.

levels in the cm- and dm- ranges
- Produce structured data, compatible with major CAD and visualization software
- Provide for internal quality control procedures, leading to absolutely reliable results

**Currently we see three major techniques, which are used in city model generation:**
**(a) Digitization of maps.** This gives only 2D information. The height of objects has to be approximated or derived with great additional efforts. It does not provide for detailed modeling of the roof landscape. This roof landscape is usually very important to the user, because city models are mostly shown from an aerial perspective. Furthermore, map data is often outdated.

**(b) Extraction from aerial laser scans.** Laser scans produce regular sampling patterns over the terrain. Most objects in city models are best described by their edges, which are not easily accessible in laser scans and often cannot be derived unambiguously. Some objects of interest do not distinguish themselves through height differences from their neighbourhood, thus they can not be found in laser data. Finally, the resolution of current laser scan data is not sufficient for detailed models.

*City modeling is maturing from a niche application into a formidable market. The growth potential is immense.*

**(c) Photogrammetric generation.** Aerial and terrestrial images are a very appropriate data source for the generation of city models. They allow the derivation of both the geometrical and the texture models from one unique data set. The photogrammetric technique is highly scalable, it can adapt to required changes in resolution and accuracy in a flexible way. The processing of new images guarantees an up-to-date model. Images are a multipurpose data source and can be used for many other purposes as well. As a result of this brief analysis, the photogrammetric approach must be considered the most relevant technique. Since fully automated extraction methods cannot cope with most of the aforementioned requirements, semi-automated photogrammetric methods are currently the only practical solutions of choice.

**There are two semi-automated approaches which have made it into the commercial domain so far:**
- **InJECT,** a product of INPHO GmbH, Stuttgart. This approach is based on the fitting of elementary, volumetric building models or, in case of complex buildings, building component models to image data. This concept, originally introduced at the Stanford Research Institute, Menlo Park, USA was refined and extended at the Institute of Photogrammetry, University of Bonn and is now available

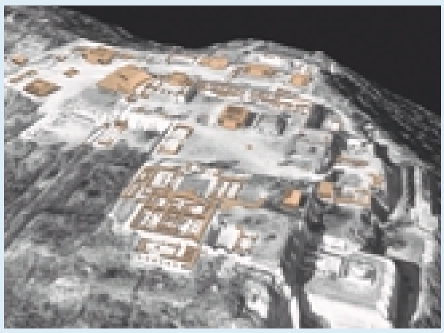


Fig.5: Maya site Xochicalco in Mexico.
Produced with the generic approach of CC-Modeler.

as a commercial software package.
- **CyberCity Modeler** (CC-Modeler), a method and software package which fits planar surfaces to measured and weakly structured point clouds, thus generating CAD-compatible objects like buildings, trees, waterways, roads, etc. Usually these point clouds are taken from aerial images, but it is also possible to digitize

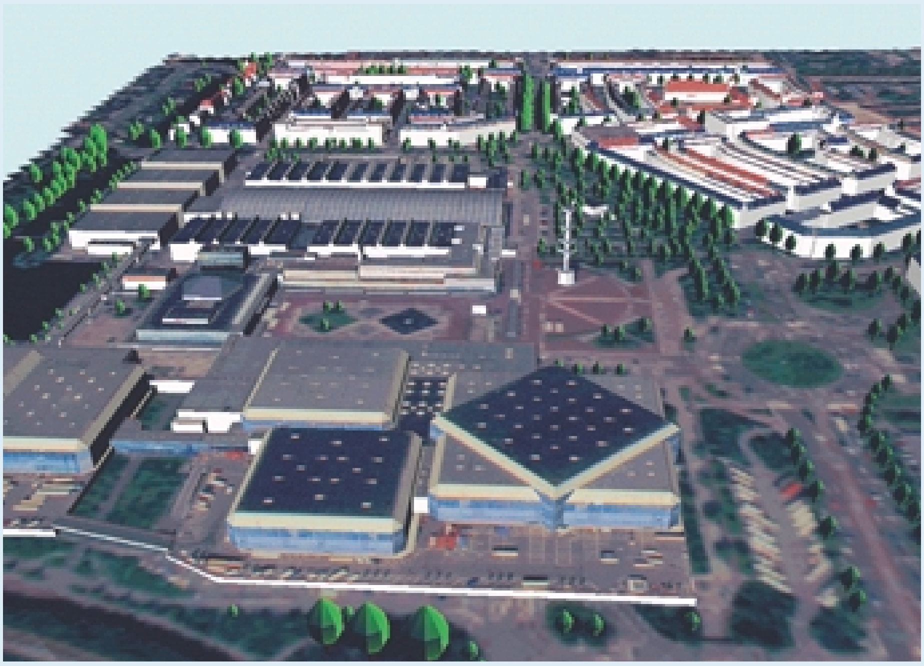


Fig.4: 3D model of the Congress Center RAI, Amsterdam. Vector data, overlaid with natural texture.

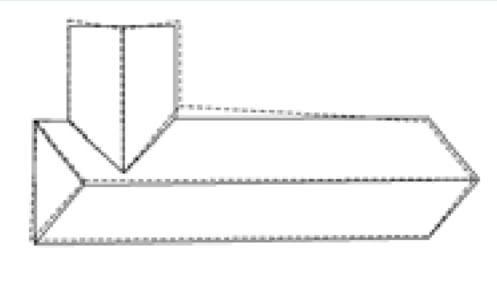


*Fig.6: Result of geometrical regularization (dotline: before, solid line: after).*

them from existing building plans. This product is marketed by CyberCity AG, Bellikon, a spin-off company of ETH Zürich.
In the following account we will focus on CyberCity Modeler.

## CyberCity Modeler

For the generation of 3D descriptions of objects from aerial images, two major components are involved. These are photogrammetric measurements and structuring. In CC-Modeler the object identification and measurement is done in manual mode by an operator within a stereoscopic model on an Analytical Plotter or a Digital Station. According to our experiences, stereoscopy is very crucial for object identification. In many complex situations in urban areas, monoscopic image interpretatation will inevidably fail. Thus the human operator defines the level of detail of representation. The structuring of the point clouds is done automatically with the CC-Modeler software. Structuring involves essentially the intelligent assignment of planar faces to the given cloud of points, or in other words, the decision about which points belong to which planar faces. This problem is formulated as a Consistent Labelling problem and solved via a modified technique of probabilistic relaxation. Figure 2 shows the data flow and the procedures involved in CC-Modeler. A detailed description can be found at our homepage www.photogrammetry.ethz.ch (Research—Projects—CC-Modeler). With this technique, hundreds of objects can be measured in a day. Although CC-Modeler is generating a polyhedral world, also objects with non-planar surfaces can be modeled in sufficient resolution (compare Figure 3). A Digital Terrain Model, if not given a priori, can also be measured and integrated. Texture from aerial images is mapped automatically onto the terrain and the roofs, since the geometrical relationship between object faces and image patches has been established. Facade texture is produced semi-automatically via projective transformation from terrestrial images usually taken by camcorders or still video cameras. The system produces its own internal datastructure (V3D), thereby accommodating vector and raster data. Interfaces to major public data formats, including OpenFlight, are available. The system and software is fully operational. Over 200 000 buildings at very high resolution have been generated already in cities and towns like Amsterdam, Chur, Firenze, Giessen, Hamburg, Melbourne, Tokyo, Zürich, in chemical plants and car manufacturer production sites. Many more projects are in preparation. Figure 4 shows the integration of vector and image raster data into a joint model (images are mapped onto the DTM, roofs and facades). Since CC-Modeler has a generic modeling approach, it is not restricted to buildings and standard city models. Figure 5 shows the 3D model of the Maya site Xochicalco in Mexico, which was also generated using CC-Modeler.

*Interesting markets are expected in the entertainment and infotainment industry*



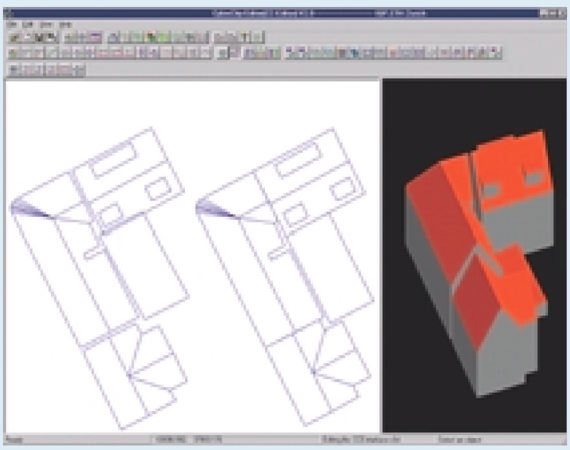


*Fig. 7: CC-Edit user interface for the correction of topological inconsistencies between adjacent buildings. Left: false topology, right: automatically corrected topology.*

## Some Recent Extensions

In its commercial implementation CC-Modeler was confronted with a number of user requirements which resulted in some additions to the original approach. These extensions in functionality are realized in the meantime and include:

- Geometrical regularization of buildings
- Editing functions for topology adjustment
- Geometrical integration of facades and modeling of roof overhangs
- Interface to OpenFlight format
- Modeling of parameterized objects (cylinder, etc)

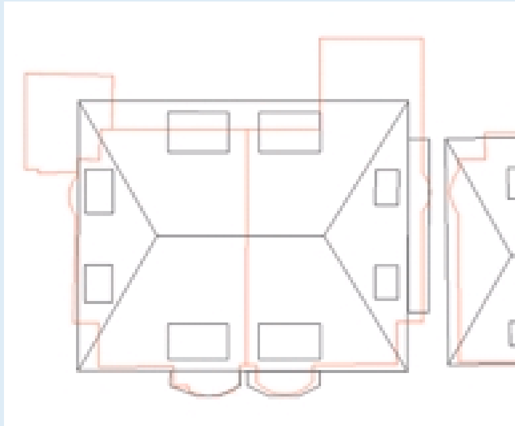


*Fig.8: Plan view of roof landscape (dark) and the related facade*

**-Geometrical regularization**

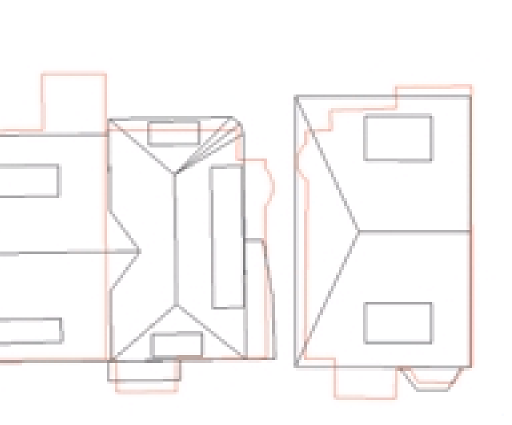
Geometrical regularization refers to the task of modifying the measured geometry in such a way that regular structures are obtained. Measurements from images are always erroneous, although the errors may be very small. In addition, and this applies in particular to older buildings, the geometry may deviate from a regular pattern significantly. Edges are not parallel, intersections not perpendicular, roof faces not planar. Therefore we have developed two solutions for regularization: a fully automated adjustment based on least-squares and a semi-automated approach of CAD editing. Both approaches are integrated into the new software module CC-Edit and offer solutions for the following requirements:

+ Same height for groups of eaves points, ridge points and other structure points
+ Parallelity of straight lines
+ Right angles of intersecting roof edges
+ Collinearity of edge points
+ Planarity of faces

These requirements can be observed simultaneously. Figure 6 shows an example.

**-Topology adjustment**

CC- Modeler was designed to handle individual buildings, one at a time, and independent from other structures in the neighbourhood. Geometrical/topological building neighbourhood conditions are not considered. Also, CC-Modeler is measuring roofs,



representation from a map (light)

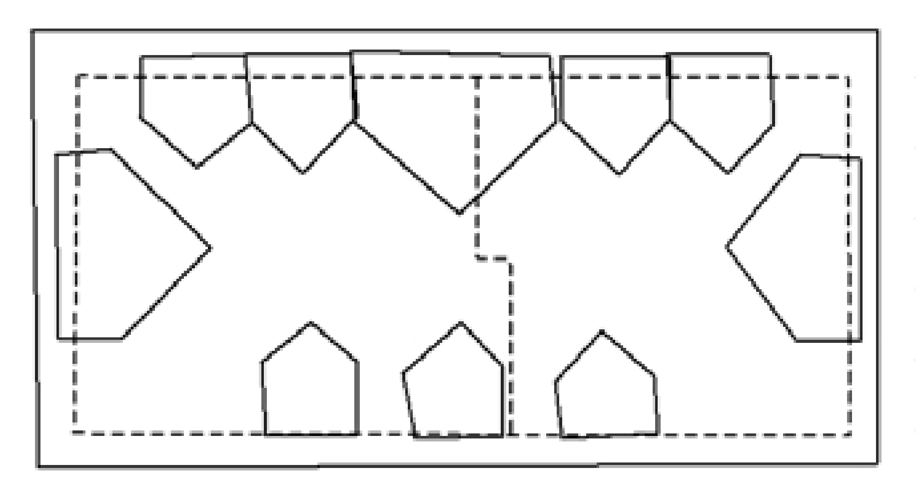


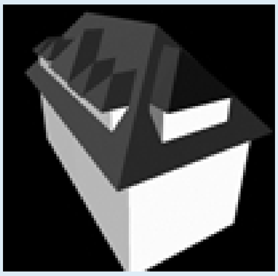
*Fig.9: Automated facade integration. Left: Plan view of roofs and facades from a map, right: integration result.*

and roofs are often overlapping each other in the xy-projection. This leads to geometrical inconsistencies, like small gaps or overlaps between adjacent buildings. These are usually not dramatic and are tolerable in many applications, especially those which are only related to visualization. However, the topological errors constitute a serious problem in projects where the 3D model is subject to legal considerations or some other kind of analysis which requires topologically correct data. For the solution we have developed both an automatic and a semi-automatic procedure. The functioning of the automated and semi-automated procedures can be monitored by an operator within an editing window as shown in Figure 7. This has a certain similarity with a CAD interface and it actually contains many typical CAD functions, but also others which are unique to our system and application-related.

**-Geometrical integration of building facades**
In some applications, the precise modeling of buildings requires the geometrical integration of facades. Facades are usually not visible in aerial images, but are available from cadastral maps. We combine this facade information with the roof landscape modeled with CC-Modeler in order to be able to represent roof overhangs. What sounds like a simple problem at first glance turns out to be a formidable task to automate. In terms of structural detail, the roof landscape looks often very different from the pattern of the facades. Sometimes the maps are outdated and the roofs do not match the map content at all. Maps may also be inaccurate to an extent that the facade appears shifted and rotated with respect to the roof by a substantial amount. Cadastral map patterns can show a lot of additional, peripheral detail, as for instance stairs and other add-ons. Figure 8 demonstrates with a practical example how much both patterns can deviate from each other. Figure 9 shows a result of automated facade integration. The problem is not yet solved in general terms and, in complex situations, still needs some manual interference.

## Conclusions

The efficient generation of 3D city models is an important task, both from a scientific and practical point of view. City models are already used in many applications and we see a steady growth of users. This is only the beginning of a long and relevant development with many opportunities for the geomatics business. City modeling is maturing from a niche application into a formidable market. The growth potential is immense. Synchronous with the broadening of the application base goes the need for higher resolution, both in terms of geometrical and textural detail. Aerial photogrammetry plays an important role as a flexible and economic technique for data generation. Semi-automated photogrammetric techniques are available for efficient data production. However, satellite images, even in high resolution mode, do not show enough detail for detailled and reliable modeling. For someone who has worked with fine-grain high resolution city models the coarse block world of earlier years bears no attraction any more. Already terrestrial images, on the other hand, are already relevant for facade texture generation, and, in the future possibly, also for facade geometry modeling and the recording of other objects which are not accessible from the air. It remains to be seen to what extent aerial laser scan data can be integrated into the data generation process. Terrestrial laser scanners do play already a significant role in the modeling of indoor scenes. The need to



combine outdoor and indoor data will thus lead to combined sensor approaches in the future. Much of the current discussion is centered around the generation of virgin data bases. It would be appropriate however to discuss now methods for data maintenance. The fast pace with which our man-made environment is changing will also require innovative techniques for the updating of 3D city models. A problem not mentioned yet in this contribution is the issue of realtime visualization. Most current commercial visualization packages are, for several reasons, not suitable for the representation of very large data sets, as they become increasingly available. If we don't see a major breakthrough in this area, this will remain a serious bottleneck in the near future and dampen a bit the excitement that comes with the generation and utilization of 3D city models.

*Prof. Dr. Armin Gruen (agruen@geod.baug.ethz.ch) is Professor for Photogrammetry and Remote Sensing at the Institute of Geodesy and Photogrammetry of ETH Zürich. His research involves many topics in Digital Photogrammetry, among those the automated and semi-automated extraction of objects from images (www.photogrammetry.ethz.ch). His group has developed CyberCity Modeler. He is the co-founder of CyberCity AG, Bellikon, Switzerland (www.cybercity.ethz.ch), a spin-off company of ETH Zürich.*

*Acknowledgement*
*Some of the developments and examples shown in this contribution have been provided by CyberCity AG, Bellikon (www.cybercity.ethz.ch).*