SEMI-AUTOMATED APPROACHES TO SITE RECORDING AND MODELING

A. Grün
Federal Institute of Technology (ETH) Zürich
Institute for Geodesy and Photogrammetry
CH-8093 Zürich
agruen@geod.baug.ethz.ch

Working Group V/3

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ABSTRACT

Automated object extraction is a key issue in photogrammetry and computer vision. For the delivery of precise, reliable and complete results human interference is indispensable. Therefore the semi-automated extraction techniques have gained much interest recently. This paper gives an overview about the status of this technology, with special emphasis on the work and results of our own group. We will limit our discussion to the reconstruction of outdoor scenes, and here in particular to the generation of buildings and complete 3-D city models. Both aerial and terrestrial applications will be covered.

> *"...the idea that extracting edges and lines from images might be at all difficult simply did not occur to those who had not tried to do it. It turned out to be an elusive problem."*
>
> Marr, 1979, p.16

> *" It must not be overlooked that segmentation is actually one of the central and most difficult practical problems of machine vision."*
>
> Davies, 1990, p. 77

1 INTRODUCTION

Site recording and modeling has been an important topic in photogrammetry from its very beginning in the middle of the 19th century on. Since then technologies have changed several times fundamentally. Today the issue of full automation of all processes involved has led to widespread research activities in both the photogrammetry and the computer vision communities. However, progress is slow and the pressing need to produce precise, reliable and complete datasets within reasonable time has had scientists and developers turn towards semi-automated approaches (compare Figure 1). While the tasks may differ in terms of required resolution (level of detail) of models, type of product (vector model, hybrid model, including mapped texture, attributed model with integrated thematic information), size of dataset, sensor platform (satellite, aerial, terrestrial), sensor and data type (images in various forms, laserscans, scanned maps, etc.), one common problem remains in all cases and that is the automated extraction of objects from images. A typical example is the task of automated building detection and reconstruction, which is difficult for many reasons.

The most common source of data are 2-D images which lack direct 3-D information. Aerial images may differ from each other with respect to scale, spectral range of recording, sensor geometry, image quality, imaging conditions (weather, lighting), etc. Objects, like buildings, can be rather complex structures with many architectural details. They may be surrounded by other disturbing man-made and natural objects. Occlusion of parts is common and the geometrical resolution may be limited. Therefore the corresponding images are of very complex content and highly unstructured. Solving the problem of building detection and reconstruction under these conditions not only is of great practical importance but also provides an excellent testbed for developing image analysis and image understanding techniques. The basic problem in object extraction stems from the fact that automated image understanding is still operating at a very rudimentary level. This applies both to close-range and aerial/space applications. However, there is a remarkable relation between image scale and successrate in extraction. At smaller image scales the level of geometric modeling becomes lower and the image context is easier to grasp since the relationships between objects are less distorted by artifacts. Thus the extraction of DTMs and objects like buildings, roads, rivers, landuse elements, etc. becomes less complicated.

Since users tend to request more and more highresolution results in 3-D modeling, the pressure is on to pay more attention to the semi-automated techniques.

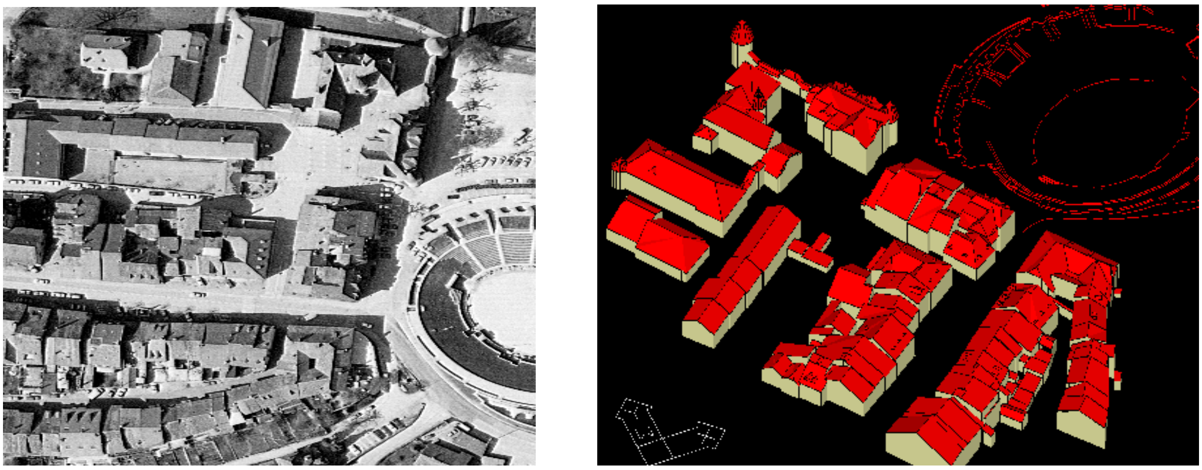

Figure 1. A case which cannot be solved automatically.
Left: Aerial image of Avenches, central town, right: 3-D model, derived semi-automatically

In this paper we will restrict ourselves to purely image-based approaches. Images inhibit a wealth of information which is yet unmatched by other sensor products. Map scanning, laser scanning, radar and other more rare techniques will not be covered. Furthermore we will focus on building extraction, because this has recently found most prominent attention. There are already a number of useful reviews and paper collections on building extraction techniques available (IAPRS, 1996, Foerstner, Pluemer, 1997, Gruen et al., 1997, CVIU, 1998, Foerstner, 1999, Wang, Gruen, 2000a). This paper is complementary, and of course will put some emphasis on our own group's work.

2 METHODOLOGY IN OBJECT EXTRACTION

Object extraction consists of three steps: detection, reconstruction and attributation. Detection refers to the process of finding a particular object in as many images as are used for further processing. Detection does not necessarily require the knowledge of the object outline, but, as a minimum requirement, should be able to produce image windows containing the outline. Reconstruction generates the 3-D geometric description of the object at the required resolution. Attributation designates descriptive elements to the object, in case of a building the type of building (apartment house, school, church, factory, etc.), a clear definition of parts of the building (chimney, dormer window, balcony, door, window, etc.), or other required information.

This sequence detection-reconstrucion-attributation could even define a processing strategy and in fact is usually equivalent to the processing sequence and represents very often a path towards increasing complexity.

At the detection level cues like color and DSM data have proven to be particularly valuable (Sibiryakov, 1996). They are used to separate in a first step man-made objects from vegetation and other natural features and then to distinguish buildings from other anthropogeneous objects, like roads, bridges, etc. Good success has been reported with isolated houses. Complex urban structures, as they exist in European old towns, still widely resist this approach.

In reconstruction we encounter a great variety of methods, depending on the type of building, level of required detail, number of images, kind of image cues and image primitives used, and utilized external and a priori information, level of automation and operator interference. There is recently a clear trend towards the use of multiple (>2) images, color cues, early transition to 3-D processing, and use of geometrical constraints. The complexity of buildings ranges from cube-shaped flat roof boxes to very complex structures with even non-planar geometrical elements. The level of detail is clearly application-dependent and goes from the joint representation of full building blocks through cube-type single height approximations of individual buildings up to a very detailed modeling with all ridge, gable and eaves points and maybe even the inclusion of chimneys, dormer windows and the like. Image cues may involve texture, color, shadows, reflection properties. Image primitives include points, double- and triple-legged vertices, linear elements, homogeneous regions. External information may come from additional sensors, DTMs, DSMs, scanned maps and GIS-resident data.

A priori information includes preknowledge about the building, its geometry and functionality (right angles, parallel/straight lines, etc.), the sensor geometry (camera models), the sun position, and the like. The level of automation in reconstruction extends from zero (complete operator measurements and structuring) to conceptionally full automation.

"Model-based extraction" is very often referred to. This is not a very helpful terminology since any kind of information extraction from images requires the use of some sort of model of the feature or object. There are different kind of models utilized (parametric, generic, functional, special) and models are used at different levels of complexity (e.g. a signalized point versus a full house).

In object extraction, as in image analysis in general, there exist two fundamentally different approaches: bottom-up and top-down. Bottom-up is a data-driven strategy, which extracts in a first step image primitives, groups them to higher level entities, and through the process of hypothesis generation and verification, builds up the complete objects. The main problem here is the instability and ambiguity of the segmentation process at the lowest level. At the higher level of object aggregation techniques from artificial intelligence, such as constraint-based reasoning, uncertainty reasoning with Dempster-Shafer, probabilistic relaxation, Bayesian reasoning, constraint satisfaction networks, semantic networks, blackboards, etc. are used.

The top-down approach, which is model-driven, usually starts with hypotheses about the scene and tries to verify their existence by compatibility checks with the existing image data. Indispensable to this technology are object models, often used in explicit form. In essence, the object data structure inferred from the image(s) is matched to the model data structure (Haralick, Shapiro, 1993). While this concept has a certain justification in robotics and navigation, where the environment might be of reduced complexity, we encounter big problems in building extraction, because here the scene knowledge is of purely generic type and the computational expense for hypotheses verification is prohibitively high.

In the more recent approaches of building extraction we see elements of both strategies used together in an interrelated manner. This seems to be the right way to approach the problem.

Other current trends in building extraction include the following aspects:

- multi-image approaches
- multi-cue algorithms
- fusion of various information sources
- Digital Surface Models (DSM) for detection and reconstruction
- derivation of DSMs by laser scanners
- generic roof modeling by decomposition into parts
- use of a priori knowledge from maps and GIS
- semi-automated reconstruction techniques

3 A STRUCTURED APPROACH TO OBJECT EXTRACTION

Figure 2 is an attempt towards systematization of object extraction strategies.

We will explain the individual strategies with procedures which our group developed over the past years. Crosscomparisons to other authors will be left to the reader.

Paths 1a and 1b take several images, one after the other, extract geometrical primitives from these single images (points, corners, lines), convert those via matching or monoplotting into 3-D features and group them into higher level entities, or in other words, establish the final model(s) through a topology generator. With our 2-D LSB-Snakes and Dynamic Programming techniques we have developed semi-automated procedures for line feature extraction from space, aerial and close-range images (Gruen, Li, 1997, Li, 1997, Li, Gruen, 1997). Our ARUBA system for building extraction works fully automatic, but successfully only under simplified assumptions (Henricsson, 1996, Henricsson et al., 1996).

Path 1b is the traditional computer vision approach. An often encountered basic version even avoids the image matching step and aims at generating 3-D data from single images, relying on additional image cues like shadows, etc. Also, the Bonn approach for automated house extraction, using essentially house corners as image primitives (Fischer et al., 1998) can be classified under 1b.

In path 2 the features are extracted simultaneously from several images, if possible under control of the camera model(s). As a result we obtain 3-D data in form of space curve segments, vector fields, or point clouds. Again, the final model has to be derived by a topology generator. An example of this class of procedures are our 3-D LSB-Snakes, which generate 3-D line objects in object space from any number of images simultaneously and semi-automatically (Gruen, Li, 1997). Seed points have to be given by an operator or taken from a GIS database. The task of the topology generator would then consist in the production of a topologically consistent road network.

On a lower level of automation (path 3) we have developed two procedures for building extraction and modeling, where the operator manually extracts an unstructured or weakly structured point cloud from a stereomodel. The systems TOBAGO and CC-Modeler then fit automatically planar faces to the point cloud and generate the complete building model.

While TOBAGO (Dan, 1996, Gruen, Dan, 1997) uses a catalogue of housemodels for the purpose of fitting, CC-Modeler (Gruen, Wang, 1998), although also driven by model assumptions, is fully generic in the sense that even other objects than buildings can be modeled, as long as they are bounded by planar faces.

Our system DIPAD (**Di**gital **P**hotogrammetry and **A**rchitectural **D**esign) follows path 4. It uses an existing CAD model of the object, however coarse, and refines it semi-automatically in an iterative fashion. This defines a hierarchical approach, where at each subsequent iteration a higher level of object refinement is obtained (Gruen, Streilein, 1994). It has been developed for close-range applications, but Streilein (Streilein, 1999) has shown that it may also be used for house extraction from aerial images. Figure 3 shows the structure of the algorithms and the data flow. The CAD model is used a priori to guide the measurement process and a posteriori to model and store the results in structured form. A detailed description of the CAD-based 3-D feature extraction procedure is given in Streilein, 1994, 1999. Figure 4 indicates several stages of the iteration procedure with an example from close-range photogrammetry (Otto-Wagner-Pavillion, Vienna).

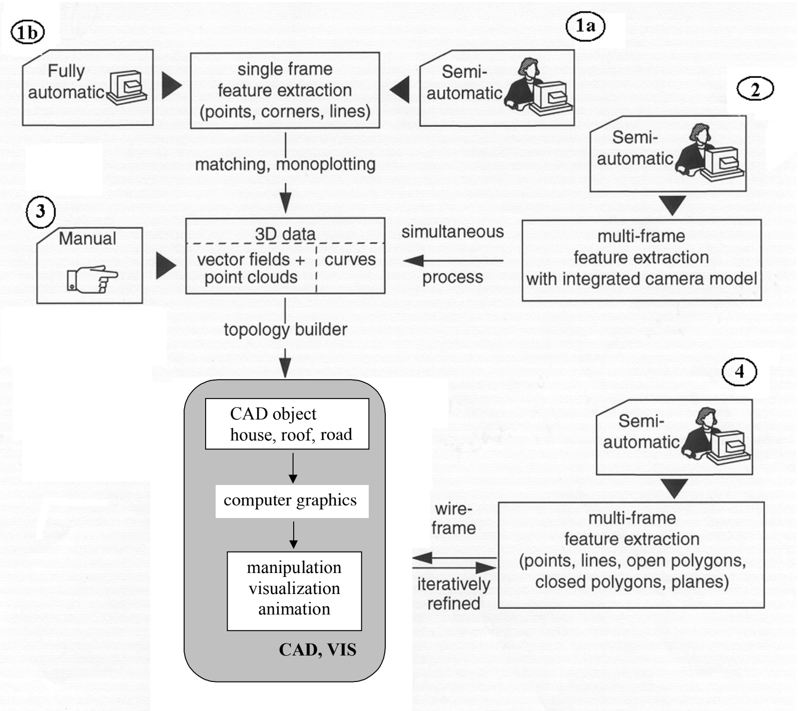

Figure 2. Automated and semi-automated object extraction strategies from aerial and terrestrial images

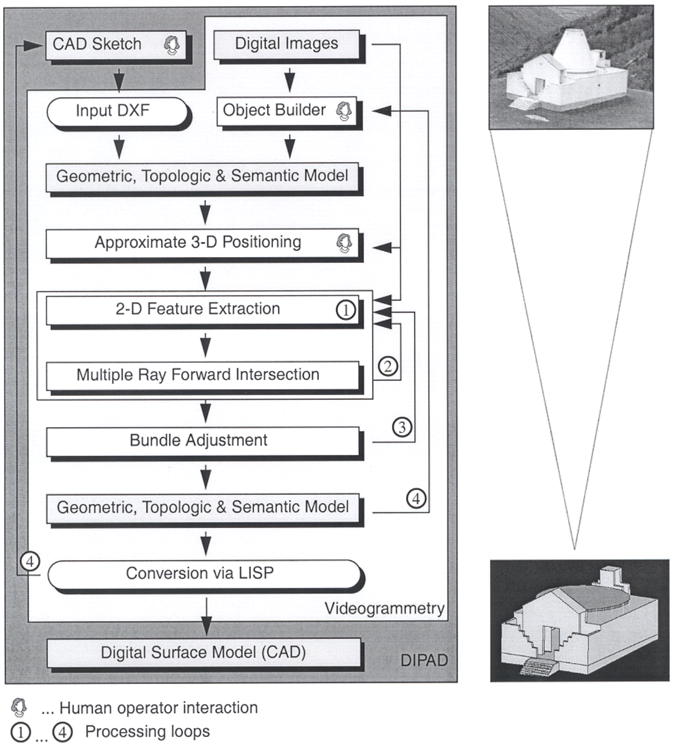

Figure 3. Flowchart of semi-automated CAD-based 3-D object extraction

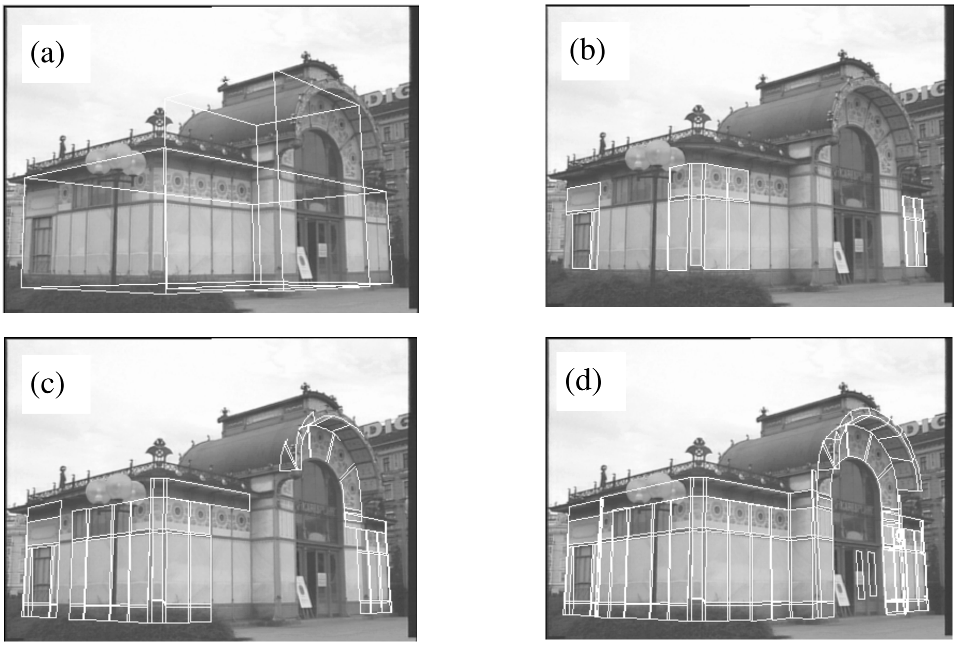

Figure 4. House extraction with DIPAD. Several stages (a-d) of the iterative refinement procedure (after Streilein, 1999)

An issue which deserves more attention in the future is texture modeling. As the quality of models improves over time more emphasis has to be put on correct texture rendering. At least for visualization purposes there exists a strong duality between texture model and geometry model. Insufficient modeling of geometry can easily be obscured by realistic texture. Videogame developers are fully aware of this fact and use it extensively in order to reduce the number of polygons in object modeling for real-time rendering. A fine approach to view-dependent texture mapping has been suggested by Debevec et al., 1996.

4 SITE MODELING AT IGP, ETH ZURICH

In recent years we have developed a number of techniques for automatic and semi-automatic site reconstruction and modeling (see chapter 3 and Streilein, 1994, Henricsson et al, 1996, Gruen, Li, 1997, Gruen, Dan, 1997, Gruen, Wang, 1998, Niederoest, 2000, Zhang, Baltsavias, 2000, Park, Zimmermann, 2000, Zimmermann, 2000). Here we will report about two new approaches, which are aiming at operational (precise and reliable) extraction of objects and are as such of special relevance to the professional practice.

4.1 ATOMI

ATOMI (**A**utomated reconstruction of **T**opographic **O**bjects from aerial images using vectorized **M**ap **I**nformation) is a project, supported by the Swiss Federal Office of Topography, Bern, to develop and test algorithms and develop operational software for the updating of road centerlines and building outlines of given digital map data 1:25 000. In addition, for building roofs one representative height has to be assigned. The map vector data is used as approximation, guiding the image analysis algorithms. The processing should be as automatic as possible, but it is accepted that some cases need manual guidance and editing (Eidenbenz et al., 2000).

For building extraction and updating the system uses multiple cues and works with color aerial images. A Digital Surface Model (DSM) and an orthoimage are automatically derived from a stereomodel. Blob detection in the DSM and unsupervised multichannel classification are used to produce approximate vector data. This allows to introduce buildings into the dataset that are not yet in the existing vector map. Multichannel classification utilizes the following information channels:

+ Shadows, derived from the S-channel of the HIS color space by thresholding
+ Channel a* from the CIELAB color space
+ Texture channel (texture measure is the number of edge pixels within a circle around a center pixel)
+ DoA (Degree of Artificiality) channel, with DoA derived from (G-R)/(G+R). DoA separates man-made structures from vegetation (Sibiryakov, 1996)
+ Channel containing the normalized DSM (nDSM = actual DSM-DTM)

Various image analysis algorithms are applied in order to improve planar location, rotation and scale of each single building. The solutions are automatically rated to keep the good results and to reject the inaccurate or wrong buildings. The building heights are taken from the DSM blobs. For details of the procedure see Niederoest, 2000.

Figure 5 shows the results of our testdataset Hedingen. For a profound evaluation of the procedure, especially concerning the amount of manual interaction, we need more experience with other datasets, which are under preparation.

Figure 5. Results of automated house updating (dataset Hedingen)

For road extraction we have proposed in earlier work the LSB-Snakes for use at small image scales, because of the relative simplistic radiometric road model involved. Under ATOMI we are required to use image scales around 1:15000. This calls for another approach for road modeling. We use for road extraction and updating also multiple cues. Finding 3-D edges on the road and especially along the road borders is a crucial component of our approach. These 3-D edges are obtained via straight line segment matching in stereopairs. The algorithm exploits the lines' geometrical and photometrical attributes and the geometrical structures. A framework to integrate these information sources using probabilistic relaxation has been developed and implemented in order to produce locally consistent matches. The proven concept of our AMOBE project for building extraction, to make the transition from 2-D image space to 3-D object space as early as possible and to have permanent interaction between the features and cues of these spaces, has been observed here as well. Figure 6 gives an overview of the cues used and the algorithms applied.

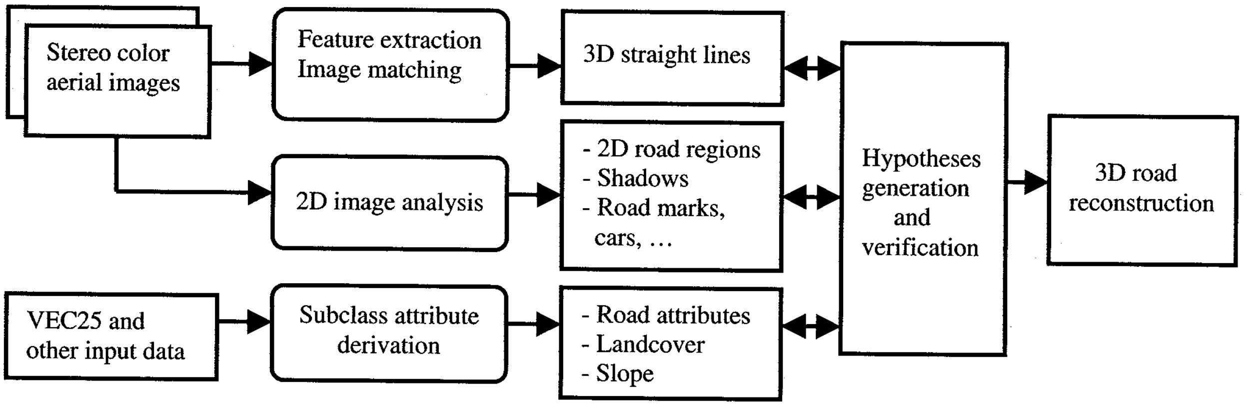

Figure 6. Cues used and algorithms applied for road extraction and updating.
VEC25…Vector data from the given map 1:25 000

Details about the procedure can be found in Zhang, Baltsavias, 2000. This is an intermediate report, with the project still in progress. Results from straight line matching are shown in Figure 7. The fact that among the 460 matches only 5 are wrong is very encouraging and gives good prospects for the further development of the system.

While manual intervention is foreseen and accepted in this procedure it is too early to argue about the required amount. A key point in our research will be the development of a metric for internal quality control.

Figure 7. Result of straight line matching in a stereopair

4.2 CC-Modeler

CyberCity-Modeler, as the name suggests, was designed as a tool for data acquisition and structuring for 3-D city model generation. From the very beginning, CC-Modeler has been devised as a semi-automated procedure. This was done in view of the need to observe the following constraints:

+ Extract not only buildings, but other objects as well, like traffic network, water, terrain, vegetation and the like
+ Generate truly 3-D geometry and topology
+ Integrate natural (real) image textures
+ Allow for object attributation
+ Keep level of detail flexible. Accept virtually any image scale
+ Allow for a variety of accuracy levels (5 cm to 2 m)
+ Produce structured data, compatible with major CAD and visualization software

In site recording and modeling the tasks to be performed may be classified according to

- Measurement
- Structuring of data
- Visualization, simulation, animation
- Analysis

In CC-Modeler the image interpretation and even the measurement task is done by the operator. The software does the structuring. For visualization, simulation, animation and analysis we largely resort to other parties', mostly commercial, software.

Figure 8 describes the work- and dataflow of CC-Modeler. The operator measures on an Analytical Plotter or on a Digital Station in the stereomodel individual points that fully describe the visible part of an object, i.e. the roof of a building. The sequence of these points may be largely random.

CC-Modeler presents a new method for fitting planar faces to the resulting 3-D point cloud. This face fitting is defined as a Consistent Labeling problem, which is solved by a special version of Probabilistic Relaxation. As an automatic topology generator, CC-Modeler is generic in the sense that any object, which is bounded by a polyhedral surface can be structured. With this technique, hundreds of objects (>500) may be measured in one day. The computation of the structure is much faster than the measurements of the operator, such that the procedure can be implemented in on-line mode. If overlay capabilities are available on the stereo device the quality control and the editing by the operator becomes very intuitive and efficient.

The DTM, if not given a priori, can also be measured pointwise.

Texture from aerial images is mapped automatically on the terrain and on the roofs, since the geometrical relationship between object faces and image planes has been established. Façade 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 3-D datastructure, including texture. Interfaces to major public dataformats are available. A pilot version of a hybride 3-D Spatial Information System (CC-SIS, CyberCity Spatial Information System) is also under development (Wang, Gruen, 2000b).

For a detailed description of CC-Modeler see Gruen, Wang, 1997. The system and software are fully operational. More than 25 000 buildings at high resolution have been generated already with this approach. Figure 9 shows one of our latest products, the Congress Center RAI, Amsterdam, location of the XIXth ISPRS Congress.

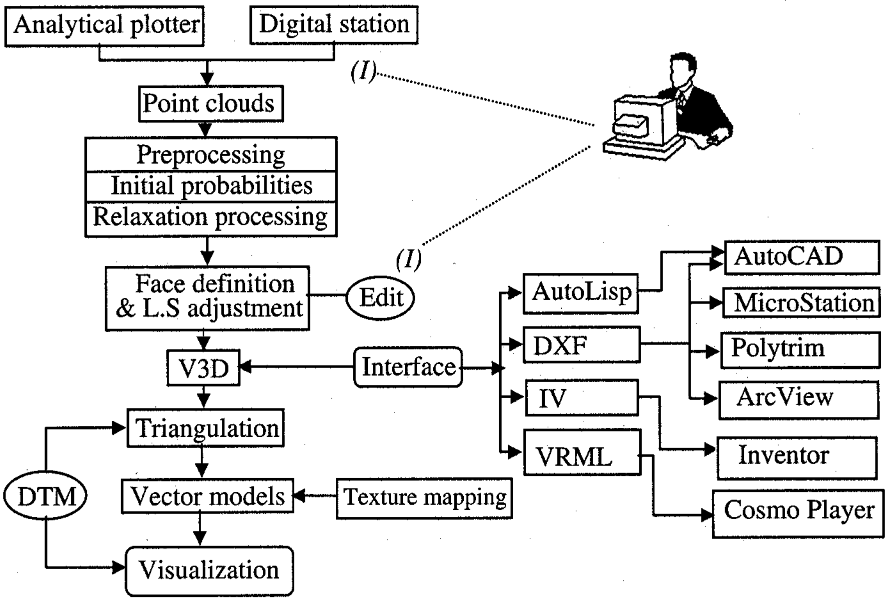

Figure 8. Work- and dataflow of CC-Modeler

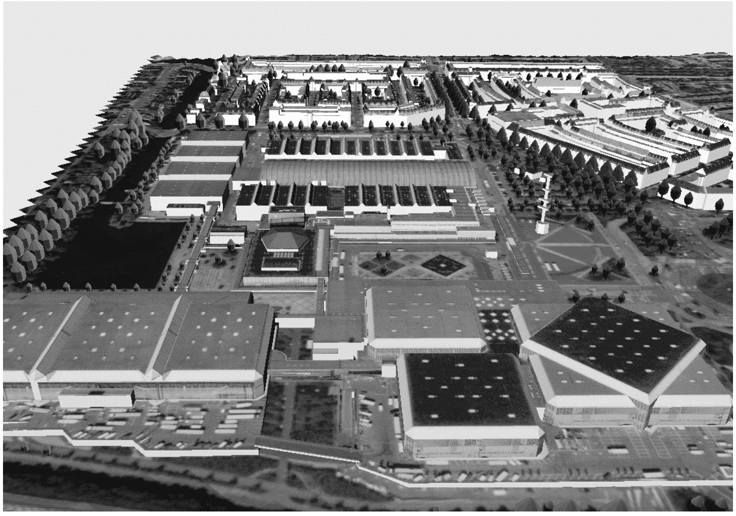

Figure 9. 3-D model of the Congress Center RAI, Amsterdam, produced with CC-Modeler (vector data, overlaid with natural texture)

5 CONCLUSIONS

Site recording and modeling from images has become a key issue in photogrammetry. Over the past 20 years or so a wealth of automated approaches to object extraction from satellite, aerial and terrestrial images has been developed. While some of these procedures work fine with highly structured images, as they are found in industrial measurement applications, they will inevitably fail in cases of complex image content. Therefore more emphasis has been put recently on semi-automated procedures, combining the human ability of image understanding with the numbercrunching capacity of computers. This has led to a number of promising approaches, some of which are briefly mentioned in this paper.

Progress on the research side is not matched yet by achievements in system development. Digital Stations are either providing only manual functions for information extraction, or the fully automated procedures show unstable performance.

One way to overcome the fundamental deficiencies in image understanding, which creates a serious obstacle towards successful automation, is simplification of the problem. This can be achieved by adding more and different kind of information to the primary data. Recently sensor and data fusion became relevant research topics. The integration of laser scans, existing DTMs, map and GIS data, hyperspectral and InSAR data shows very first promising results. However, when developing new approaches to object recording one should keep in mind that user specifications do not remain unchanged over time. We see already now an increased request for highresolution data. As an example, in central Europe there is already a remarkable demand for buildings with modeled overhanging roofs. Also, facility management applications require a detailed modelling of the interior of buildings. The requirements for high level of detail, both in terms of geometric and texture models, must lead to a critical evaluation of our extraction methods.

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