ON THE PERFORMANCE OF SEMI-AUTOMATIC BUILDING EXTRACTION

Eberhard Gülch, Hardo Müller, Thomas Läbe, and Lemonia Ragia
Institute of Photogrammetry
University Bonn
Nußallee 15, D-53115 Bonn, Germany
Ph.: +49-228-73-2904, Fax: +49-228-73-2712
E-mail: ebs@ipb.uni-bonn.de

Commission III, Working Group 4

KEY WORDS: Matching, Parametric Models, RANSAC, Quality Control

ABSTRACT

A Semi-Automatic Building Extraction system using two or more digitized overlapping aerial images has been enhanced by increased automation for the measurement of saddle-back-roof buildings, hip-roof buildings and boxes. All newly developed modules have been incorporated in the object oriented design of the system. The new methods consist of a ground-point and roof-top matching tool and a robust determination of shape parameters, like e.g. gutter length and width. The current performance of building extraction is quantitatively and qualitatively evaluated. We examine the increased efficiency using the automated tools, the success rate of individual modules and the overall success rate using a combination of methods. A methodology for quantitative comparison is tested on footprints of buildings from classical stereo measurements and from semi-automatic measurements. A qualitative comparison in 3D of multiple measurements of complete buildings is performed on three different datasets.

1 INTRODUCTION

We describe our experiences with a Semiautomatic Building Extraction System which has been developed since 1993 at the Institute for Photogrammetry, University of Bonn. This system was presented in several publications since 1993 (Lang and Schickler, 1993, Englert and Gülch, 1996, Gülch, 1996, Gülch and Müller, 1997, Gülch, 1997, Müller, 1997, Müller, 1998).

The original system had been extended to the measurement of volumetric primitives (Englert and Gülch, 1996), migrated to an object oriented design (Gülch and Müller, 1997), and enhanced by various automation tools and tested on large datasets (Gülch, 1997, Müller, 1997, Müller, 1998). A primitive can be a complete building model, like a saddleback-roof or hip-roof building or a part of a building, depending on the image scale and the required level of detail. Since several years, we do have methods to measure the height of single primitives which require an already form adjusted model in one image, or methods to perform a final fine-tuning adjustment which requires very good approximate values. Having observed also difficulties on measuring the ground height (we currently assume a horizontal ground plane) caused by disturbances in the close vicinity of the buildings we had to develop new methods to overcome those problems. We have decided to automatically determine height *and* form parameters of the primitives, requiring only very few operations by the user, and adopted the classical way of measuring ground heights in the neighborhood (if not inherited). Both methods are described in detail in (Müller, 1997) and (Läbe and Gülch, 1998). The algorithms have to be fast enough (some seconds) to be applicable in this prototype system for on-line measurements. We can accept that time, if we otherwise need less manual operations. The goal for the newly developed automation is first of all directed to speed up the measurement process with a high success rate in sub-urban areas, with not too dense structures and an image scale in the order of 1:5000 to 1:15000. We focus right now on basic building types, like saddleback-roof or flat-roof buildings representing a large percentage of buildings or building aggregates. However, other primitives can be handled in exactly the same way. In chapter 2 we describe the current status of the system and the actual work flow.

One task of evaluation of performance is to monitor the increased efficiency of new tools in terms of time and the success or failure rate of the automated parts themselves. These internal checks are needed to identify remaining problem areas. The external performance, checked against classical measurements is needed for acceptance in practice. We have started to develop methodologies for quantitative comparison, right now focused on 2D footprints and qualitative comparisons in 2D and 3D based on visual inspection.

In chapter 3 we will present the tests for the individual automated modules and the monitoring of increased performance. In chapter 4 we present first results of a quantitative comparison of ground plans measured by two different methods and qualitative comparisons of 3D models from three different periods. We conclude with an outlook on further investigations and developments.

2 THE SEMI-AUTOMATIC SYSTEM

The acquisition process is controlled by a human operator, who interprets the image contents and measures the 3D-shape. Automated tools assist the operator. In the following we discuss the currently implemented tools with emphasis on the automated parameter estimation.

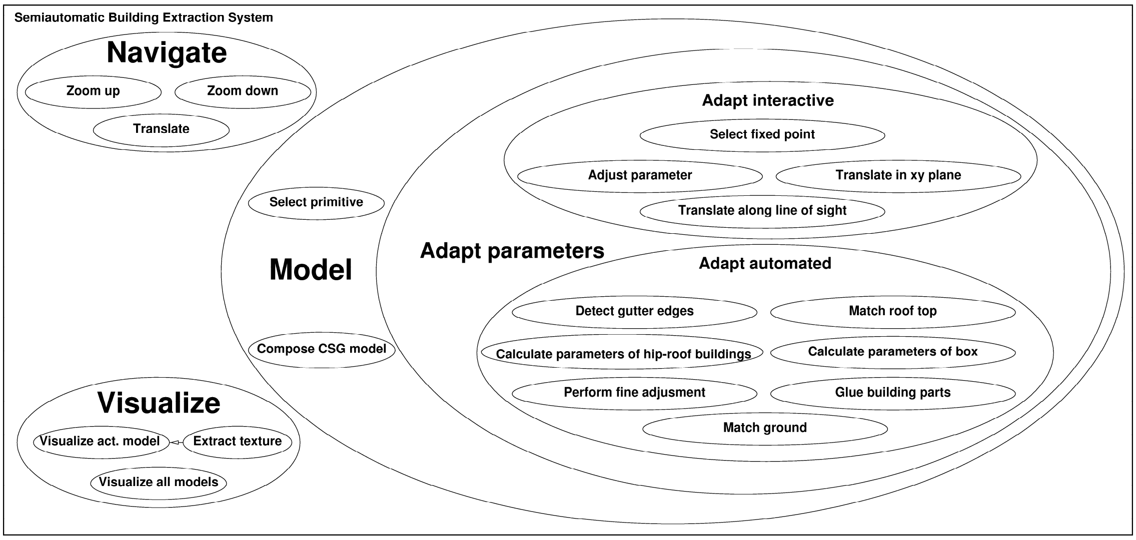

Figure 1: Use Cases of the Semiautomatic System.

2.1 Software Design

Developing a semiautomatic system is a complex process, that requires constant integration and updating of software modules and user interfaces. It requires a management of complex tasks and objects and of huge amounts of data. It is a long term process, which should make reuse of well established existing modules possible and allow for full extensibility. Maintenance and portability are of utmost importance for future applications. To facilitate these processes we apply an object-oriented design for the software involved. Figure 1 shows the implemented use cases. The system can now be used as a *executable Program* or as an *Application Programming Interface (API)*. In the first case, the operator acquires data using the *Graphical User Interface (GUI)* of the system (cf. Fig. 2), in the second case, the programmer is able to extend the system or to integrate the system in own software, using the object-oriented class structure of the API (Gülch and Müller, 1997).

2.2 Navigation

The input data of the system is a set of aerial images, from which an image pyramid was processed and their orientation data. Patches from two of these aerial images are simultaneously visualized in the workspace of the operator. The operator is able to change between the resolution steps of the pyramid and the position of the image patch with some mouse clicks.

2.3 Modeling tools

Automatic as well as interactive systems need an internal model of the objects to be acquired. Buildings show an amazingly high diversity in structure which is increasing due to new styles being developed or invented. However, a large percentage of buildings show regularities which allow to describe them using a small set of rules. A Constructive Solid Geometry (CSG) representation of parametric models has been proved as a practical internal model (Müller, 1998).

2.3.1 Selection of Primitives. In our model representation CSG-primitives are parametric models which are classified into several types. These types differ in their geometry and set of parameters. Examples of the currently implemented ten types are saddleback-roof or hip-roof. The first interaction step of modeling is to select one of these types. After this selection a projection of the parametric models into the screen windows takes place. The models are shown as wire-frames. For this process previously processed orientation data of the images is used. Each parametric model is specified by a set of parameters. Values of these parameters have to be adapted either manually or automatically.

2.3.2 Parameter Adaptation - Manually. The interactive adaptation of the form and pose parameters is performed in monocular mode. Stereo display is not necessary. The adaptation of the parameters is done in a sequence of steps, each specifying one or two parameters of the model. The parameters are changed in dependence of the sequence of two points specified by mouse clicks and in dependence of the type of primitive. Therefore the number of interaction steps is between 50 % and 100 % of the number of parameters. The interactive height adaption is performed by dragging a slider that moves the defined model in one image, along the rays defined by the model points and the projection center until the model fits in the other image(s). In this way, not only a single point is measured, but all visible model lines are used to adjust the height, by adapting them in the other image(s). This method is faster and more reliable than measuring homologous points. We can reach a gross time of about 70 sec per primitive using this slider compared to 86 sec by measuring homologous points.

2.3.3 Parameter Adaptation - Automatically. The difference between an Interactive and a Semiautomatic System is given by the automated tools integrated in the Semiautomatic System. These automated tools support the interaction process and accelerate the acquisition of data. The automation processes run online and should not block the operators interaction. Therefore runtime behavior of these tools is a critical property.

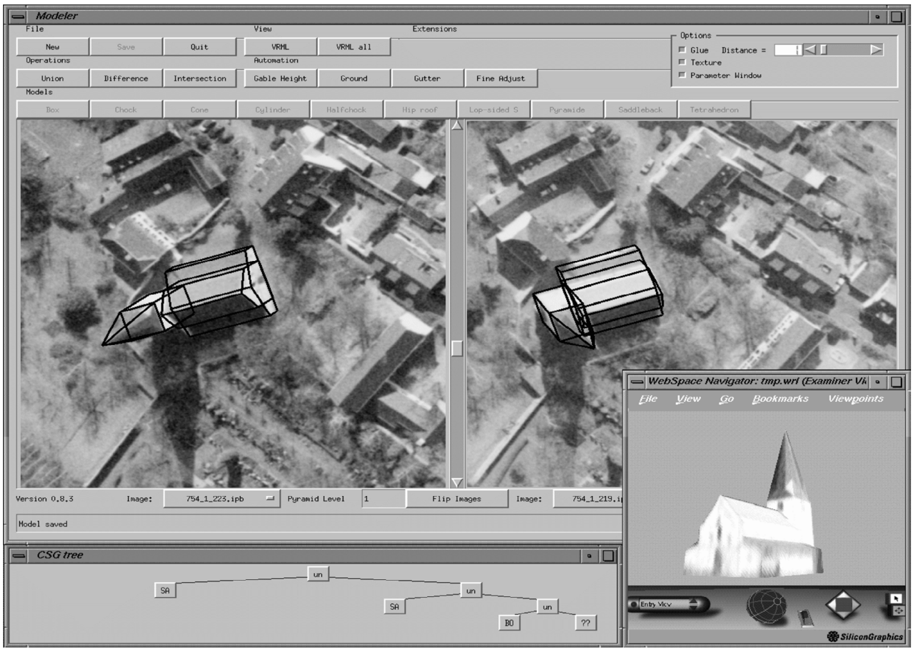

Figure 2: Graphical User Interface (GUI) of the Semiautomatic System.

The line segments in each image are computed off-line and are loaded during the interaction for the part of the images where the actual measurement takes place. These line segments are used by some automated tools.

Following automated tools are actually integrated:

Ground point and roof top matching. To automatically compute the absolute height of the top of a roof or of the ground we use cross-correlation on the grey values of the images with an epipolar search strategy (Müller, 1997). This can be compared to classical point-transfer in Photogrammetry.

RANSAC. The *RANdom SAmple Consensus* principle can be used as a powerful technique to determine a best fit of building parameters from a given set of image edges. An activity diagram of the RANSAC procedure for measuring a hip-roof building is shown in Figure 3. The procedure starts with calculation of edge sets out of image edges, which are candidates for unknown model edges. The building parameters are calculated from an edge sample, whose edges were randomly chosen from each edge set. After a range check the weight of the computed model is calculated using fit of image edges. This procedure is repeated until the weight all possible samples is calculated or a threshold for the number of samples is reached. The building parameters with the best calculated weight are chosen as the result of the process. RANSAC is currently used for form parameter estimation (e.g. gutter height, width and length) for saddleback-roof, hip-roof and flat-roof buildings as well as for height determination of flat-roof buildings.

Clustering. Another robust method to estimate parameters is *Clustering*. Clustering is highly recommendable for problems with few unknowns and a high redundancy (Förstner, 1989). Clustering has been applied to determine gutter width and height for saddleback-roof buildings and to compare it with the RANSAC approach. Within the algorithm a n-dimensional array is used where n is the number of unknown parameters (here $n = 2$). Each parameter has to be discretized. Therefore a finite parameter space is required and the result may be not accurate due to the discretization. Every value of the array is the weight for the special combination of parameters represented by the array indices. While computing the result of the robust estimation every observation is taken into account. Every observation leads to a set of possible combinations of parameters which correspond to the observation. For these combinations the weight is increased. In the most simple case the combination of parameters with the best weight is chosen as the solution.

Fine adjustment. An *automatic fine adjustment* (Läbe and Ellenbeck, 1996) by a robust spatial estimation, using all line segments in all images provides an optimal fit of the selected model to the image data.

2.3.4 Composition of a CSG model. After adapting the parameters of the primitives, the operator is able to compose a CSG tree by selecting one of the three logical operations *union*, *difference* or *intersection*. The actual acquired CSG model is shown as a tree (cf. Figure 2).

Describing a building by the combination of primitives or combined primitives requires a precise “docking” of the primitives (Englert and Gülch, 1996). This docking is supported by matching and glueing facilities. The former allows to match at least two edges of different primitives and the latter matches and glues exactly two faces of different primitives together.

2.4 Work flow of form and pose estimation

To summarize: the operator has to perform in the best case three or four operations only for measuring *basic building types* which is less than in the case of classical photogrammetric point measurement. Two of the operations are simple *selections* and not *measurement* tasks.

In the case of a *saddle-back-roof building* four operations are needed: *select* the building type (saddle-back), adjust

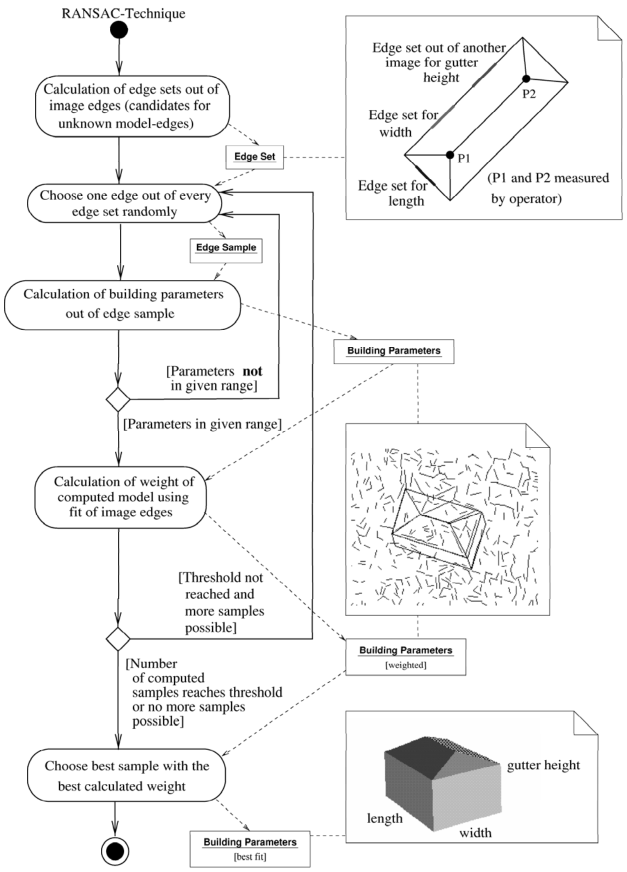

Figure 3: RANSAC Technique applied to the measurement of a hip-roof building.

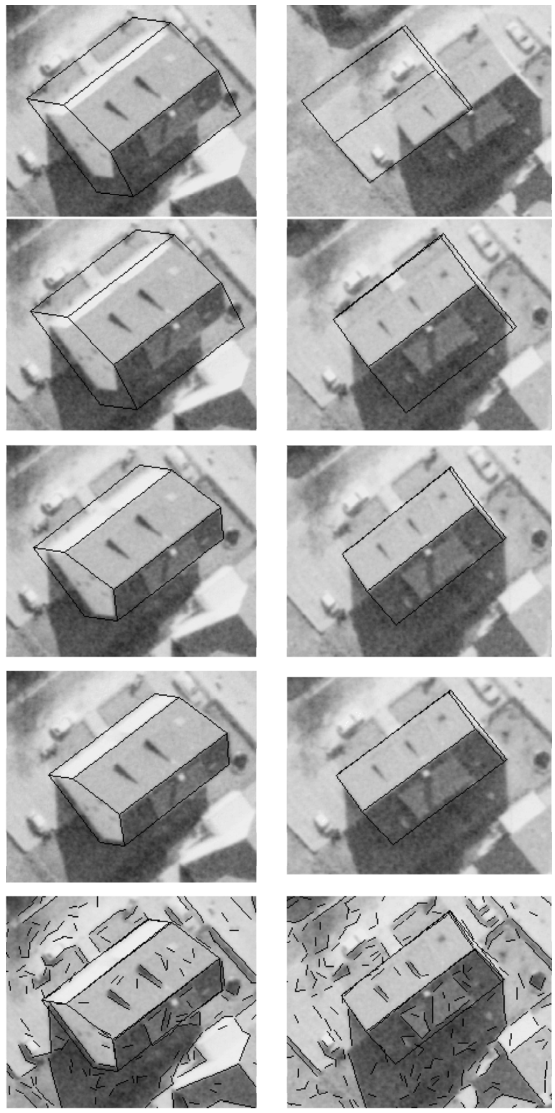

Figure 4: Example of measuring a saddleback-roof building. **1st row:** Operator measures two gable points in the left image. **2nd row:** Automatic roof-top height. **3rd row:** Automatic gutter matching. **4th row:** Automatic ground height. **5th row:** Fine adjustment and result.

the 3D model (primitive) of a saddle-back to *two points* (two gable points) in one image, thus determining the rotation around the Z-axis, and the length of the building and finally *select* one ground point in the vicinity (in one image) and the system automatically determines the remaining four unknown parameters: a) the absolute roof height, b) the ground height, c) the width of the building and d) the gutter height. The absolute roof height and the ground height are independently determined by cross-correlation and epipolar search. The detection of the gutter height and the determination of the width of the building is done by Clustering or RANSAC. An example of the different steps is given in Fig. 4. A final robust adjustment of all parameters of each volumetric model in all images can further improve the overall result.

The general operation-flow for the *lop-sided saddleback-roof building* is similar to the symmetric saddleback-roof building. The absolute roof height and the ground height are separately determined by the cross-correlation module, and the remaining parameters are computed by the RANSAC technique. The difference is that the lop-sided saddleback-roof building has one additional parameter (or five unknown parameters): Because of the missing symmetry of the roof-top two widths have to be calculated in the RANSAC procedure.

In the case of a *hip-roof building* the operator performs practically the same operations: select the building type (hip-roof), adjust the 3D model (primitive) to two points (two roof top points) in one image, thus determining the rotation around the Z-axis, and the length of the roof top and finally selects one ground point in the vicinity (in one image) and the system automatically determines the remaining five unknown parameters: a) the absolute height of the roof top, b) the ground height, c) the length of the building, d) the width of the building, and e) the gutter height. The search for length, width and gutter height is performed by a RANSAC technique.

In the case of a *flat-roof building (box)*, even less parameters have to be given: the operator selects the building type (box), adjust the 3D model (primitive) to one point (one corner point) in one image, and finally selects one ground point in the vicinity (in one image) and the system automatically determines the remaining five unknown parameters: a) the absolute height of the flat roof, b) the ground height, c) the length of the building, d) the width of the building, and e) the rotation around the Z-axis. The search for all parameters except the ground height is performed by a RANSAC technique.

2.5 Visualization

A visualization of the results is done by generating a VRML (Virtual Reality Modeling Language) file of the building models and exporting it to a VRML-browser. There are several kinds of visualization available: (a) visualization of all extracted models, (b) visualization of the actual model or (c) visualization of the actual model with extracted texture.

3 TESTING AUTOMATED MODULES

Each of the automated modules as well as the combination is tested for the success rate. The efficiency is compared to earlier versions of the system.

3.1 Success rate

All modules for automated parameter estimation are investigated concerning their success rate. We distinguish between a) full success without any further intervention by the operator, b) one ore two additional attempts or c) failure, which requires a more or less complete correction and manual adjustment by the operator.

3.1.1 Datasets. We have started to examine the modules on two different datasets. The first dataset A consists of a pair of two aerial images with moderate to good image quality. Within the second dataset B (from the project described in (Läbe and Ellenbeck, 1996)) we use image patches of the buildings to be measured. For every building 6 image patches exist. As Figures 5 and 6 show the image quality from dataset B is much lower than the one of the image pair (A). In both datasets the image scale is 1:12500. Dataset A is scanned with 12.5μm, dataset B with 11μm pixel size. So the ground resolution is comparable. In both datasets the density of buildings is moderate. There is enough space nearby to select a suitable ground point. The buildings are of different size ranging from about 75m^2 to more than 500m^2; there are single buildings or buildings connected to others. Some buildings have disturbances and they are partly surrounded by bushes and trees. There have been measured parts of complex buildings as well. No approximate values for the unknown parameters were used, but we define a certain range for the parameters for the RANSAC approach. For that purpose we have decided to work in object space units for higher flexibility and better understanding. We have chosen slightly different ranges for the different building types to be able to check the influence. The values are the same for all examined buildings in all datasets except the absolute roof height range in case of a box which is set different in the two datasets. But the setting of this parameter is not very critical, as the range is usually known from the flight plan, but of course the setting influences the performance of the parameter estimation.

3.1.2 Correlation. The test for the correlation procedure has been performed on the roof-top and on ground points separately on saddleback and hip-roof buildings in both datasets. In the case of a roof-top we use only one trial as the point is chosen automatically between the two given precisely located roof-top points. For the 109 *roof-tops* it works well (up to 87% success rate) as long there are no big disturbances due to e.g. chimneys right on the roof top.In case of failure the operator measures the height manually.

For the *ground height* determination several trials are possible because the success depends on the "intelligent" choice of the point. There must be enough texture and no 3D disturbances around that point. Here big differences between unexperienced (not documented here) and experienced operators can be observed. The high success rate for the ground points (83%) in a first test on only 30 buildings is mostly due to the skills of that operator in selecting a "good" point. Further investigations are necessary on the effect of training on the performance of that module.

3.1.3 RANSAC and Clustering. The RANSAC and the Clustering approaches are tested with the datasets A and B. In a first attempt the automated procedures are started. For the second and third attempt the operator could change the used images and/or in case of a box select another corner point or run the procedure once again. The success rate is counted as success after maximal three attempts (details in (Läbe and Gülch, 1998)) with the operator accepting the result.

Some examples of successful and false determination of the parameters computed by the RANSAC algorithm in both datasets are shown in Figures 5 and 6.

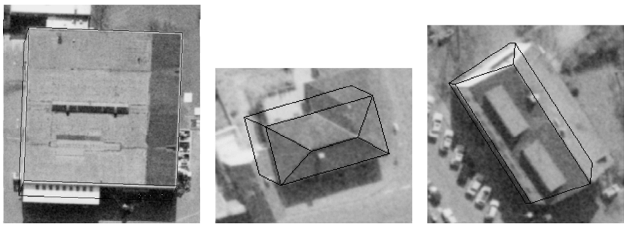

Figure 5: Examples for RANSAC algorithm results in dataset A. Two successful measurements and one failure (wrong gutter height and width).

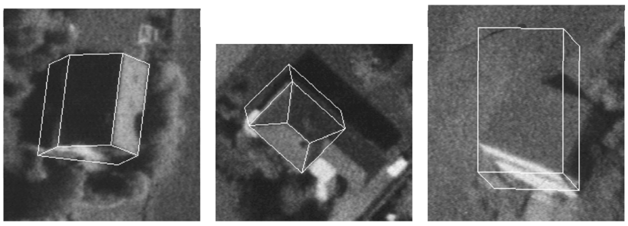

Figure 6: Examples for RANSAC algorithm results in dataset B. Two successful measurements and one failure (wrong rotation, length and width).

The success rates for about 160 saddleback-roof buildings (up to 80 %) and the 46 hip-roof buildings (up to 88 %) are extremely promising, whereas the calculation of the parameters of the 55 flat-roof building (box) is problematic (up to 43% success rate). The performance for the lop-sided saddleback-roof (not documented here) is expected to be similar to the saddleback-roof and the hip-roof buildings.

The results show, that the influence of a lower image quality (like in dataset B) can not be compensated by a higher amount of image patches.

For the *saddleback-roof building* we compare the Clustering and the RANSAC methods. Both methods give similar results. We favor, however, the RANSAC approach for better extensibility and the potential of handling a much higher amount of parameters. Using the RANSAC approach we can further see that additional attempts by changing the image used to select the samples improve the results.

A better performance of the *hip-roof buildings* in dataset A (only 12% failure) compared to dataset B (34% failure) is most probably due to the higher image quality. Even if we have to estimate one parameter more for the hip-roof building compared to the saddleback-roof building we get a comparable or even better performance, as we have chosen slightly more restrictive parameter ranges for the hip-roof building.

The current algorithm for finding the parameters of the *box* has additional problems. The operator gives one corner point only and the computer has to find edges which begin at this corner and belong to the roof of the box. Using a normal edge extraction it is clear that extracted line segments are not connected to the corner point itself. So the search area around the point has to be large which leads to more false image edges. Often short image edges which are near a corner point are the reason for a bad estimation of the rotation around the Z-axis. Then the other parameters of the box can not be computed either correctly. The box in Figure 6 (right) can serve as an example for failure of that type. A solution would be to give an edge instead of a corner point as a start information, which would not increase the amount of operations for the user. The amount of successful second and third attempts for the box is very large compared to the number of successful first attempts. This is a hint for a too low threshold for the number of samples computed in the RANSAC loop. This means we had assumed a too low number of outliers when determining that threshold. We are expecting a significant higher success rate for the first attempt when we increase this threshold. On the other hand side of course the computation time for *all* boxes will be longer.

3.1.4 Combining methods. In the dataset A we examined the determination of all four unknown parameters (roof height, ground height, gutter width and height) of 30 *saddleback-roof* buildings but without the final adjustment step (cf. Table 1). In this test we applied correlation for the heights and Clustering for the gutter parameters in a predefined strategy. As a result 10 of the buildings were correctly adjusted in the first attempt, 8 buildings required the manual adjustment of 1 parameter only. For 11 buildings we applied the Clustering procedure between 1 and 3 times and we finally needed to adjust between 1 and 3 parameters manually. For one building the procedure did not work at all (cf. saddleback-roof building in Fig. 5).

With the same image material we tested the overall procedure (without fine-adjustment) to determine all five parameters (roof height, ground height, gutter length, width and height) of 10 *hip-roof* buildings. The results show an even better behavior: 6 of the buildings were correctly measured with 1 attempt only, for the remaining 4 buildings, we had to correct 1 parameter (mainly the gutter width) and once to choose another ground point.

A general problem for the height determination either by correlation or the robust techniques are image edges which are parallel to the epipolar lines. In those cases we currently require operator assistance and manual measurement.

The question of operator strategy is still open. When the first automatic attempt fails the operator must decide if he tries the automatic procedure again or if he adapts the missing parameters manually. It is as well a compromise between computation times and time for manual adjustment. There is still a lack of experience to select the optimal strategy.

Success	SB	HR
Total	30	10
Correctly adjusted	10	6
Manual adjustment of 1 parameter	8	4
1-3 iterations or 1-3 parameters	11	0
Complete failure	1	0

Table 1: Success rates of combination of parameter estimation tools (Correlation and Clustering/RANSAC) for saddleback-roof buildings (SB) and hip-roof buildings (HR).

If the selected model does not fit well to reality the result will be some kind of generalization, which means the operator has to accept it or choose the proper model instead. The optimal way depends of course on the task and the available resolution provided by the image material.

3.2 Efficiency

For the gross acquisition time we monitor the navigation through the image and image pyramids, the model adaptation times and the time for creating the constructive solid geometry tree of building parts. Table 2 shows the increased efficiency in the acquisition process from about 120 seconds to about 40 seconds per primitive, counted as gross acquisition time. With more training on the automation tools and the strategy we expect even better results at least in sub-urban areas.

4 QUANTITATIVE AND QUALITATIVE COMPARISONS

Having buildings extracted by two different methods or at different times or with different operators we need a method to compare the resulting representations and check for completeness. The methodologies for comparison developed so far follow two lines: a quantitative approach and a qualitative approach based on visual inspection. We aim at comparing to ground truth, but due to lack of such information we develop the methods for comparison of measurement procedures of similar accuracy level. In all cases we currently refer to the identical object or to parts of it and take the identification of corresponding objects a given. The current strategy of quality control is directed towards online re-measuring selected buildings visualized in the Semi-Automatic System, which would solve the correspondence problem.

4.1 Comparing 2D footprints

First we focus on 2D footprints to develop the methodology for the comparison of two measurements of the footprint of the same building (like in Fig. 8). For a *qualitative* comparison we use an overlay method of 2D polygons presented in a VRML browser for visual inspection. For a *quantitative* comparison we use probability densities to describe the imprecision of measurements and the uncertainty of abstraction based on a method developed to determine topological relationships between imprecise spatial objects from two independent datasets (Winter, 1996). Details of the this approach are given in (Ragia and Winter, 1998). The

Version	Project	Details	Complexity	Primitives	Sec./Primitive
-1995 Hase	Different Areas	Suburban-urban	medium	249	**124.8**
1996 Hase+	Oedekoven I	Suburban	high	5499	**86.4**
1996 Hase+	Frankfurt I	Downtown	high	549	111.5
1996 Hase+	Rostock	Urban	high	371	149.6
1997 ObEx0.7.1	Oedekoven III	Suburban	high	525	**70.0**
1998 ObEx0.8.2	Oedekoven IVsmall	Suburban	medium	29	**41.0**

Table 2: Increased efficiency due to automation.

distances between the two boundaries along the so called zone-skeleton are computed. The distances characterize the deviation from being equal. The discretized distance function along the special skeleton can be represented as a histogram as shown in Fig. 7 and Fig. 8 (2nd row).

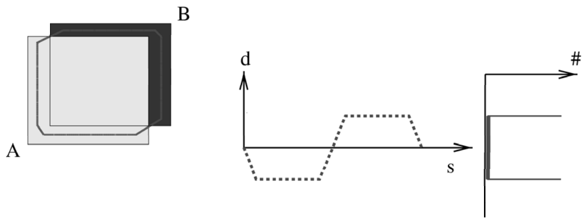

Figure 7: Quantitative comparison of two overlapping areas using an histogram of distances *d* to the zone-skeleton.

We get values of $d < 0$ for $A \setminus B$ and $d > 0$ for $B \setminus A$, which enables to distinguish between these two cases.

A Gaussian histogram indicates similarity, a bi-modal histogram indicates systematic errors (like translation), and a biased histogram indicates missing or additional parts (abstraction) or gross errors.

An example of a real dataset is given in Fig. 8. We can see that the area of the first measurement (A) contains the area of the second measurement (B) to a large extend (negative d). The second area contains the first one only partly (positive d) and there is a large difference in the form (d<-0.8m). It is in principle possible to introduce the different accuracy levels of measurements into the process to improve the method. This method still needs extensive testing, further elaboration and extension to 3D models.

4.2 Comparing 3D models

For a *qualitative* comparison of 3D models from at least two measurements we use the Virtual Reality Modeling Language. The extracted 3D primitives are transformed in VRML format and visualized with a VRML-browser, that allows the 3D viewing and walk- or fly-throughs of the extracted scene. For the 3D visualization of extracted building parts we use different colors and transparency mode to a) detect gross errors in e.g. height measurements and b) to study and visually compare the chosen selection and combination of primitives. Results from three different measurements of the same building are given in Figures 9 and 10. In Fig. 9 we can see a good result with practically the same generalization level and the same parameters in all measurements. In Fig. 10 we have a bad result. One operator had forgotten an essential part of the building complex (box lower left). Also the roof-top height of one part differs by several meters from the other two measurements and the reality. For the inspection of large amounts of data we certainly need a pre-processing step that focus the operator's attention only to the critical cases. Such a method can

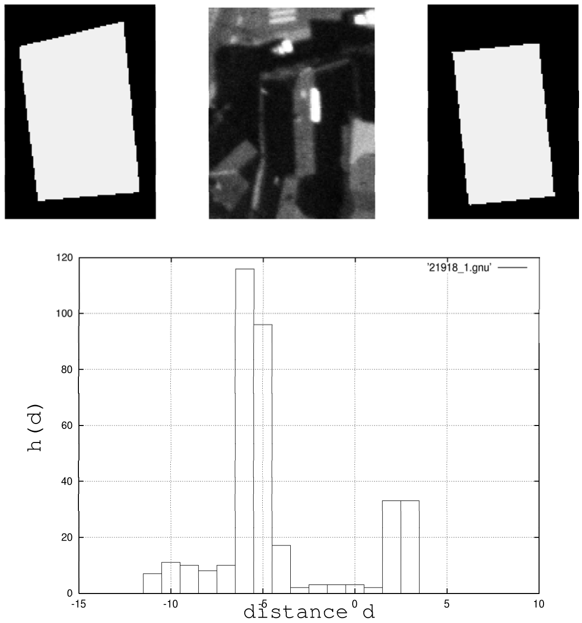

Figure 8: 2D - quantitative comparison of footprints. **1st row:** Area (A) Measurement at an Analytical Plotter, Image patch with building, Area (B) Semi-automatic measurement. **2nd row:** Histogram of the morphological distances in [dm] between the skeleton and the boundaries of the building from the two measurements (image by courtesy of T-Mobil and Aerowest).

be based on the developed approach described above, but still needs to be designed and implemented.

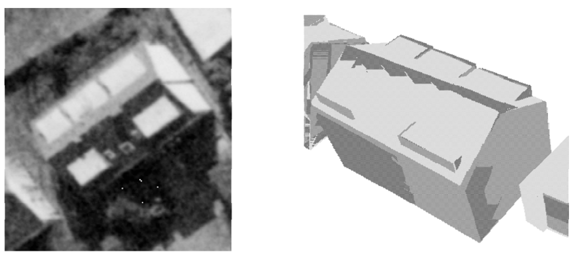

Figure 9: 3D - qualitative comparison. Good result, as all three measurements differ only slightly.

4.3 Completeness

Concerning the check of completeness of measurements we follow two strategies: (a) the visualization of old measurements in the Semi-Automatic System with the potential of on-line correction or additional measurements by the operator (supported by the automated tools) and (b) a more automated approach based on image matching in urban areas with commercial software and automatic analysis of the

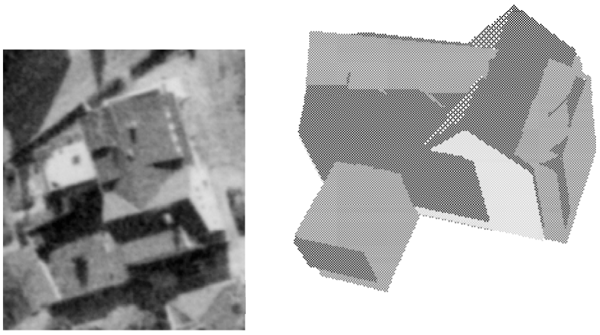

Figure 10: 3D - qualitative comparison. Bad result, as all three measurements differ very much.

resulting digital surface model. Both strategies are currently investigated on two different datasets.

5 CONCLUSIONS

We have presented a prototype system for the efficient semiautomatic extraction of 3D building information from imagery with a high degree of detail in urban and suburban areas. We rely on the human operator to solve the interpretation, but we supply automated tools that efficiently support the interaction. The presented methods for robust estimation of pose and form parameters of volumetric building models from digital imagery have been evaluated on more than 250 buildings. The chosen strategy to support the operator with automated on-line tools seems feasible. From the psychological point of view we believe it is a better way to introduce automation than letting the operator only to correct the results calculated off-line by the computer. Due to the integration in an interaction environment the algorithms can be used and tested even if the success rate of single modules (up to 88%) in suburban areas has no yet reached a status which can be described as "works in nearly all cases". For the saddleback-roof and hip-roof buildings the results of the tests fulfill our expectations. For the box the search strategy should be changed. For this building type the minimum number of parameters which the operator has to give has already been reached. For the saddleback-roof and hip-roof buildings the possibility to reduce the operator action to the measurement of one point exists. To generally increase the success rates for the robust techniques more information sources than only image edges may be necessary.

Besides an initial acquisition of 3D buildings the updating process (change detection) as well as the validation and editing of 3D models derived by other methods will be of increasing importance in the future. We regard the developed system a suitable tool to perform these tasks. With the developed and envisaged methodologies for quality control based on quantitative and qualitative tools we should be able to perform a fast inspection.

The increased efficiency during the development is very promising, but we still lack the empirical comparison of time measurements to classical photogrammetric methods on large datasets. Due to the lack of international tests on a broader basis we currently perform such a test in cooperation with a company .

Our developments show an increased performance in semiautomated building extraction, with the real potential as an easy-to-use measurement and inspection tool.

ACKNOWLEDGEMENTS

This research is supported by BMBF/DARA GmbH under Grant 50 TT 9733 and by the Landesvermessungsamt Nordrhein-Westfalen. We thank Andreas Barden and Tim Spangenberg for assisting in the measurements.

REFERENCES

Englert, R. and Gülch, E., 1996. One-eye stereo system for the acquisition of complex 3D building descriptions. GIS.

Förstner, W., 1989. Robust methods for computer vision. In: IEEE Computer Society Conference on Computer Vision an Pattern Recognition, IEEE Computer Society.

Gülch, E., 1996. Extraction of 3D objects from aerial photographs. In: Proceedings COST UCE ACTION C4 Workshop 'Information systems and processes for urban civil engineering applications', Rome, Italy, November 21-22.

Gülch, E., 1997. Application of semi-automatic building acquisition. In: A. Grün (ed.), Automatic Extraction of Man-Made Objects from Aerial and Space Images (II), Birkhäuser, Basel.

Gülch, E. and Müller, H., 1997. Object-oriented software design in semiautomatic building extraction. In: Proceedings Integrating Photogrammetric Techniques with Scene Analysis and Machine Vision III, Orlando, Florida, April. SPIE Vol. 3072.

Läbe, T. and Ellenbeck, K.-H., 1996. 3D-wireframe models as ground control points for the automatic exterior orientation. In: Proceedings ISPRS Congress, Comm. II, Vienna, IAP Vol. XXXI.

Läbe, T. and Gülch, E., 1998. Robust techniques for estimating parameters of 3D building primitives. In: Proceedings ISPRS Symposium, Comm. II, Cambridge.

Lang, F. and Schickler, W., 1993. Semiautomatische 3D-Gebäudeerfassung aus digitalen Bildern. Zeitschrift für Photogrammetrie und Fernerkundung 5, pp. 193–200.

Müller, H., 1997. Designing an object-oriented matching tool. In: 3D Reconstruction and Modelling of Topographic Objects, International Archives of Photogrammetry and Remote Sensing, Vol. 32, ISPRS Commission III/IV Workshop, Stuttgart, September 17-19., pp. 120–127.

Müller, H., 1998. Experiences with semiautomatic b uilding extraction. In: 3rd Course in Digital Photogrammetry, Institut für Photogrammetrie, Universität Bonn and Landesvermessungsamt Nordrhein Westfalen.

Ragia, N. and Winter, S., 1998. Contributions to a quality description of areal objects in spatial data bases. In: Proceedings ISPRS Comm. IV Symposium, Stuttgart, Sept. 7-10. Accepted for publication.

Winter, S., 1996. Unsichere topologische Beziehungen zwischen ungenauen Flächen. PhD thesis, Landwirtschaftliche Fakultät der Universität Bonn, DGK-C 465, München.