INTEGRATION OF AUTOMATIC PROCESSES INTO SEMI-AUTOMATIC BUILDING EXTRACTION

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ABSTRACT

The modeling of three-dimensional objects is a current topic in digital photogrammetric research. The modeling of buildings in digital imagery or digital surface models involving automation processes has reached a level where it can compete with classical photogrammetric stereo measurements. There are many different ways on how to integrate automation. We describe our system and its automated features that support the operator in the adaption of parametric models to multiple overlapping images. There do exist tools to automate the measurement of heights, to automate the estimation of the form parameters or for the handling of building aggregates. With such tools we can reach about 20 seconds for the modeling of a volumetric primitive which is fully comparable to the currently used photogrammetric methods.

1 INTRODUCTION

The extraction of 3D object information from 2D image data or from digital surface models is one of the current challenges in Digital Photogrammetry.

With digital or digitized data we have the potential to automate the process of feature extraction at least to a certain extent. We aim at improving the efficiency or better at reducing the costs at the same high accuracy level, that traditional photogrammetry offers.

We currently focus on the extraction of geometric information, as we still lack tools to derive semantic information on an operational level, however, there are promising developments on the way to attack this problem.

We focus here on the extraction of building information (3D) in topographic applications on a very general level, i.e. a large range of image scales, a large number of applications, a huge variety of input data and auxiliary data types. In this context we are not interested in specific methods, tuned for a very limited number of applications or just one single application or just one single type of images.

There are many ways possible to integrate automation. Already since several years we are developing, extending and improving a semi-automatic system for building extraction (Englert and Gülch, 1996), (Gülch, 1997). We have chosen an approach using multiple images, operator guidance and the assistance of automated modules to perform a certain number of measurement tasks. To put this system into context, we can compare it with two European developments (Grün and Wang, 1998) and (Brenner and Haala, 1998), which have reached operational status, the first one being available commercially. The method by (Grün and Wang, 1998) uses stereo viewing and point type measurement on digital images similar to digital photogrammetric workstations, but in addition an automatic roof-part generation method from the measured roof-top and gutter points. A set of planar roof faces is adjusted to the measured point cloud. The method by (Brenner and Haala, 1998) uses digital surface models from laser altimeter measurements and given 2D ground plan information as input. Several parametric building types can be modeled automatically from these data and edited or extended by human interaction.

All discussed methods offer automation that goes beyond the classical stereoscopic measurement on an analytical plotter or a digital workstation, but they require different input data, operator skills and offer different output.

In the following we want to show how certain modules of our semi-automatic building extraction system are integrated into the work-flow. We will demonstrate how the modules have speeded up the extraction process and give our views and experience using this approach. We have chosen image scale and requirements typically asked for by mobile phone companies.

2 MEASURING BUILDINGS IN IMAGE DATA

The task in our examples here is to model buildings with a limited number of types (e.g. flat-roof, pent-roof, hip-roof, saddleback-roof). This means we allow a certain degree of generalization.

2.1 Traditional way

We want to measure 3D coordinates of a building like in Fig. 1 and model it with a 3D model 'Saddleback-roof building'. In classical photogrammetry we would measure six corner points of the building and one point on the ground, if we do not intersect with an existing DEM. There are of course other possibilities as well, if we introduce certain assumptions and constraints.

If our resulting 3D model must have rectangular structures or a horizontal roof top lines, we have to do some post-processing. If we have measured points on a hip-roof building and want to model with a saddleback-roof building we need to generalize. Furthermore we must correct for small measurement errors.

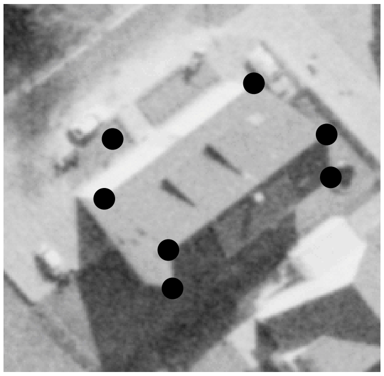

Figure 1: Measurement of the seven marked points to derive a saddleback-roof building (done in STEREO-mode.)

2.2 Fitting wire frame models

In our system the task for the operator is to fit a wire-frame model of the selected type to the images in monoscopic viewing. The system can handle several images, currently two are displayed at once. The input to the system consists of oriented, overlapping images. The operator chooses one of the images and adjusts the parameters of a wire-frame model to the image data. Figure 2 shows the user interface of the current version which has so far been used in more than a dozen of projects, amongst others now also the acquisition of topographic control structures for the automatic orientation of aerial images in orthophoto production (Läbe and Ellenbeck, 1996). The operator needs at least two images to adjust to the correct absolute height. If only one image is available, other information like given ground height is required to derive a complete 3D model. The basic workflow has been described earlier in detail (Englert and Gülch, 1996), but has been elaborated further.

There are several possibilities to adapt such a parametric wire-frame model to image data and we currently distinguish three ways to do so:

1. a purely manual adaption,
2. a guided adaption and
3. an automated adaption.

This sequence reflects increased automation, and with successful adaption, certainly an increase in speed.

2.2.1 Manual adaption of a wire-frame model. In the case of purely manual adaption we take the example of a saddleback building (cf. Fig. 3, left part). We show one possible way, of course the operator is quite free do use an own, different sequence. We pick one gable point of the model (operations 1,2 = two mouse clicks) and drag it to the building. We keep the point fixed and adapt rotation around z-axis and the length, i.e. we fix the second gable point (operations 3,4). We then keep the second gable point fixed and fix the gutter height and building width (operations 5,6).

We have observed that most of our operators, which are assistants and students, perform the adaption of this model in that way. This offers a potential increased performance by automating this sequence.

Finally we adjust the ground height by keeping the gutter point fixed and dragging the point at the base to the correct position (operations 7,8).

2.2.2 Guided adaption of a wire-frame model. As an optional way, the system guides the operator in a new way around the described operations 1-6 and switches then automatically back to the manual adaption. The operator, having selected the model type "Saddleback-roof" just clicks on the point in the image (operation A) and the model is moved automatically to it, he/she points on the second gable point and rotation and length are adapted (operation B). The third point is given (operation C) and the gutter height and building width is adjusted. The remaining task requires the same type of operation as above (operations D,E). We can see from the comparison to the purely manual method, that we can reduce six operations to three. We are, however, aware of the fact, that we need to insist on a certain sequence, which is for sure acceptable, if e.g. only very few building types occur, like in telecommunications applications today. It is furthermore justified by the experience gained so far, which proofs a considerable speed-up.

The guidance can be designed to each operators comfort, e.g. to choose as the third point in the sequence not the gutter point to the right of the gable line, but to the left. The philosophy in all cases is, that the operator can go back to purely manual measurement at all times.

We have purposely not included steps 7,8 (or E,D), as we might not be able to see to the ground at that point. We rather measure at another corner or chose a point in the vicinity.

2.2.3 Automated adaption of a wire-frame model. We have developed a method to adjust form parameters and heights using extracted image edges (extraction is done a priori) and a very limited number of points provided by the operator (Läbe and Gülch, 1998). The sequence for a saddleback-building is given in figure 4. The operator selects only two points on the roof-top (1st row) and one point on the ground. With correlation and robust methods for form parameter adaption we get the model fixed in form and position. A final, optional fine adjustment using all edge information in all images can further improve the result.

2.3 Measuring absolute heights

We need the information from at least two overlapping images to derive the absolute height.

2.3.1 Homologous points. We have monoscopic viewing and we can do this by manually selecting one point in one image and identifying the corresponding or homologous point in the other image(s). This process is connected to the classical point wise measurement of photogrammetry.

2.3.2 Slider. Having the parametric model fitted to the image data in one image, only one degree of freedom, the absolute height remains to be solved. Instead of measuring a single point, we want to use the complete wire-frame to adjust it in the right image or all other images. To do this a slider was introduced visible in Fig. 2 in the middle bar. By moving the slider up and down we can adjust the correct height of the wire frame model from the left image in the right image, or in all the other available images. A considerable increase in speed was observed using this technique instead of measuring a single homologous point.

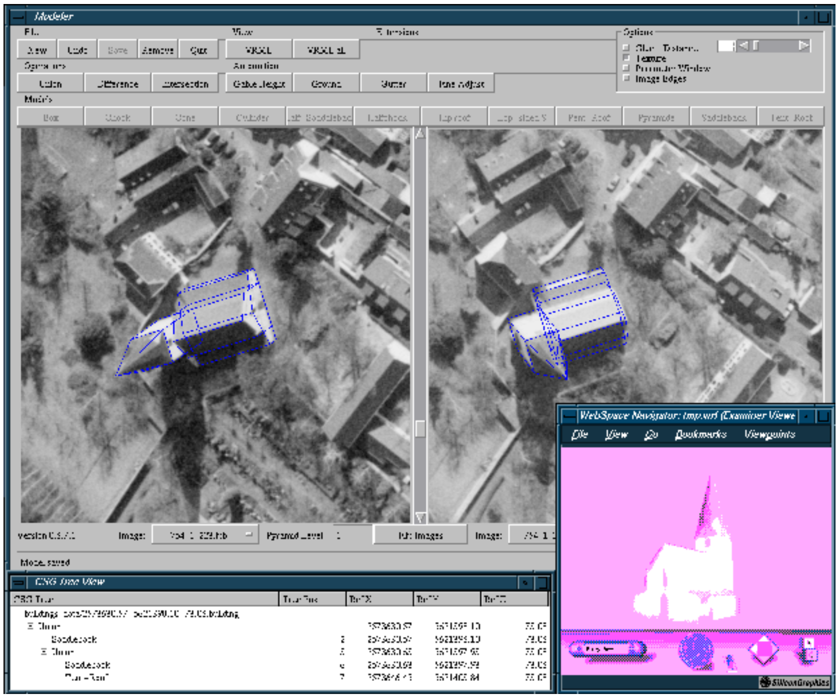

Figure 2: Graphical user interface

2.3.3 Correlation. Some modified image correlation algorithms are used to measure the roof top height and the height of points on the ground. The latter is used to define the ground height of a building, in case it is not possible to adjust the wire-frame to points directly at the wall.

The selection of the point is different in those cases. For ground height the operator selects a point in the vicinity (cf. circle in figure 5). The operator needs to define a point without 3D disturbances in the correlation window and this requires a certain experience. In our example (left image in first row of figure 5), we can see that the ground height is not adjusted yet. In the 2nd row in figure 5 the ground height has been measured by correlation (left image). From the right image we see, that the absolute height is not adjusted yet, indicated by the arrow. For roof-top heights a point between the gable points is defined automatically. With the roof-top matching module the height is adjusted (3rd row).

Good experiences has been made with these techniques. The success rate for the roof-top matching is higher and reaches usually 90%.

2.3.4 Error handling There do exist cases, where some of those methods or all fail. Correlation works fine in most cases. We certainly need the possibility to define a ground point near by to determine the ground height of the building, as sometimes the basis of the wall is occluded or hidden behind vegetation.

If correlation of roof top fails, we adjust manually with the slider. If the correlation of the ground height fails, we measure at another point near by or adjust directly by dragging the wire frame model.

The adaption of form parameters works for about 50-90% of the 250 investigated buildings. The method usually does not perform a complete search. This means, we can run a higher number of samples for the robust adjustment, if the computer power allows. If we have only one parameter wrong in the first iteration we simply correct this single parameter manually. We certainly need and we provide a manual editing/correction step for all tools.

2.4 Handling building structures

Up to now, we have shown how to handle single primitives. Having this functionality available, we focus on the handling of complete structures, i.e. on the combination of primitives by using CSG (Constructive Solid Geometry) tree and functions working on complete trees to speed up the modeling process further.

2.4.1 Union-Difference-Intersection. Single 3D primitives can be combined by the logical operations UNION, DIFFERENCE and INTERSECTION to a CSG structure. This structure can be processed by standard software to a polyhedral structure, i.e. a BREP representation (e.g. ACIS, www.spatial.com).Now more complex structures can be visualized **and** analyzed. Figure 6 shows how a building complex with an inner yard can be modeled easily: Two flat-roof primitives (boxes) are used with the operation DIFFERENCE. The upper part of the figure shows the wire-frame models in one image (note: the hidden line mode is not active here) and the resulting 3D view as a snapshot from a VRML (Virtual Reality Modeling Language) browser.

Figure 7 shows how a non-rectangular structure can be modeled. If we do not have a single primitive available to model such a building complex, we can combine two primitives using the operation INTERSECTION in this case. In the upper part the two primitives (again no hidden lines) are visible. In the lower the resulting 3D model is displayed. Please note, that for the left primitive we only need to define the right border line precisely, whereas the right primitive needs to be adjusted correctly with the upper, left and lower border. The right hand side of this primitive is not critical.

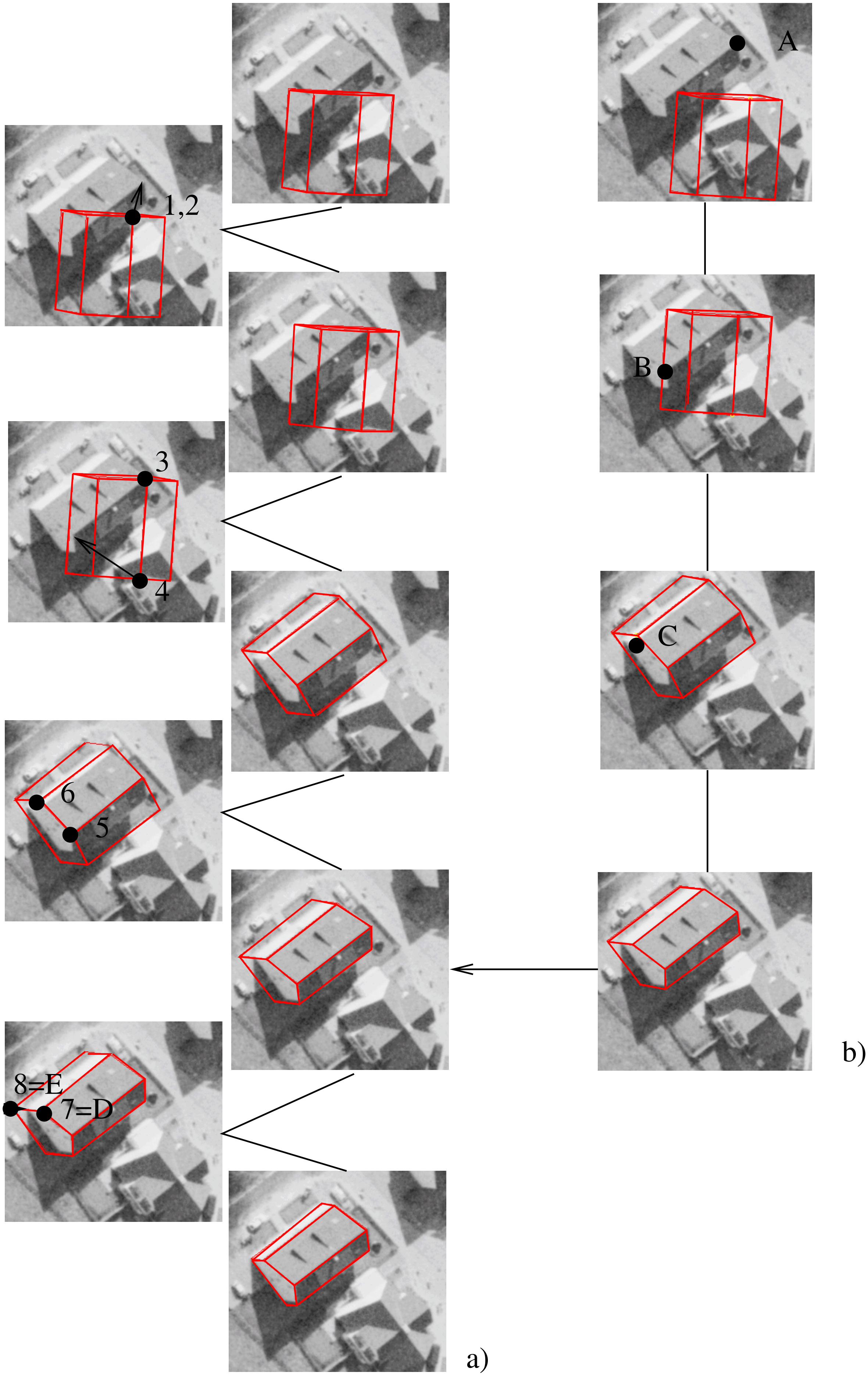

Figure 3: Two ways of adapting form parameters. Only the left image is shown in both cases. Labeled points indicate manual interaction. **a)** Manual adaption. The steps are given top-down. The wire frame model is displayed at each stage, **b)** Guided adaption, which after three operations (A-C) switches back to the manual adaption.

2.4.2 Measurement of polygonal objects.

As we have earlier observed problems in dense built-up areas with many polygonal objects, which are in principle possible to model with the current tools, but require substantially higher efforts, we can use the CSG tree principle and a newly developed method to measure polygonal objects as well. This measurement is guided. Instead of a fixed polygonal primitive we are on-line generating a polygonal model by a set of primitives with flat roof and four corners, which do not need to form a rectangle (cf. Fig. 8a)). We assume the border line of the real building to be of polygonal type and having constant height. We require the building to be modeled by pointing at the corner points in sequential order, e.g. clockwise. The corresponding CSG tree is generated during the mensuration of the single points. In Fig. 8a)-d) we see how the first for corners are connected and how the next primitive (Fig. 8e)) is started. During the adaption the ground height and the absolute height can be adjusted like with a single primitive. The result is a polygonal structure consisting of single primitives with the same height and connected by the operation UNION (Fig. 8f) visualized in a 3D view given in Fig. 8g).

2.4.3 Inheritance, copying, editing.

Inheritance of parameters from previous buildings, and the possibility to copy and edit complete CSG structures are three very essential functions.

Having made very good experience in several years with the inheritance of parameters of single primitives (e.g. size and absolute height) we found further substantial increase in efficiency by using copying functions for complete structures, i.e. also to inherit the parameters of a complete CSG tree. Especially in suburban areas we often encounter similar structures, e.g. row houses or the combination of house and garage, differing only in position and height, may be also in rotation. By copying complete structures like in figure 9 we can dramatically reduce acquisition times. In the case presented, we only needed to translate the structure instead of measuring the four primitives (with operations UNION) again or measure the 12 corner points like in classical photogrammetry.

The advantage is, that the operator can still adjust single elements or the rotation around the z-axis, in case there are slight differences from one housing complex to the next one. In addition the height will have to be adapted in case of sloped terrain.

2.4.4 Gluing.

One possibility is the optional gluing of two primitives if the second one is within a certain range from the first one. Gluing of single parameters or of faces is possible. In figure 10 a flat roof is moved towards a already acquired saddleback-roof building. The activated gluing connects the flat roof building to the wall of the first one. In the lower example a roof part is adjusted to the underlying flat box.

Gluing is currently mainly used if we want to avoid gaps or overlaps in xy-plane. The current version has shown certain limitations concerning gap-free roof parts in very complex situations.

2.4.5 Visualization and texture mapping.

We can start an on-line process of texture mapping to support the acquisition phase if we have very complex CSG-structures. In Fig. 2 we can see in the lower right hand side the window of a VRML browser with the currently acquired 3D model.

3 EXPERIENCE AND RELATION TO TWO OTHER APPROACHES

We have made good experience with the integration of automated tools in the building extraction process. This has already earlier been documented, e.g. (Gülch et al., 1998, Läbe and Gülch, 1998). The determination of height values is working sufficient well and fast enough to give a real support. However, the method of (Brenner and Haala, 1998) has advantages as a direct 3D information is inherent in the used laserscan data. But it requires on the other hand side a given ground plan of rectangular type.

The increase in performance is documented in table 1. We can now reach about 20 seconds per 3D primitive. This is a figure which is fully comparable to the classical way of photogrammetric building acquisition. It is certainly valid for suburban areas and the above mentioned assumption of telecommunications applications.

We are so far not aware of any other investigation about public comparisons between such a new digital method and classical photogrammetry. Compared to the method described by (Grün and Wang, 1998) with a time of 400-500 roof units per day, which means about 60 seconds per roof part, our method has advantages in suburban areas (about 20 secs per primitive), but has most probably somewhat longer acquisition times in dense urban structures. A concrete statement is difficult, as there is so far no comparison on the same image material and task available.

If we have to model very complex buildings in downtown areas, with many small details we have certainly still some unsolved problems. The above mentioned gluing function is not always sufficient to get a homogeneous, gap free and overlap free roof landscape if we combine primitive by primitive in the above mentioned way. This can now at least partly be solved by using the ACIS tools to really perform difference and intersection operations. Based on our first experience in such image data, we have developed new models, like e.g. non rectangular ground plan for a saddleback roof to cope with these challenges and to ease the combination of primitives in building block type structures. Yet another step to attack that problem is the described polygonal measurement with automatically tree generation. This method is fast and we stay in our standard CSG structures. If the assumption of a polygonal building with flat roof is correct, then we can solve the task. If we have additional roof structures, we need further modules to integrate those. A very interesting solution is the roof face adjustment part of the method proposed by (Grün and Wang, 1998) which is certainly very suitable for very complex roof structures.

The combination of tools is optional in our system. We can have different default combinations depending on the application and the operator. In the newest version of the software (OBEX1.0) these modules can be loaded during runtime on demand. The operator is, however, at all stages in the position to interact and perform a purely manual fitting of the models.

If we summarize the most important features of the three methods (cf. table 2), we can see that each of them has different requirements on input data, on operator skills and advantages in certain areas and disadvantages in others. But common to all three methods is the need and the availability of editing and correction tools to improve the results obtained by the automated parts which take place at different stages in the three examples.

Version	Project	Details	Compl.	Prim.	Sec/P.	Remark
-1995 Hase	Diff. areas	Suburb-Urban	medium	249	**124.8**	Basic version
1996 Hase+	Oedekoven I	Suburb	high	5499	**86.4**	CSG
1996 Hase+	Frankfurt I	Downtown	high	549	111.5	CSG, one image only
1996 Hase+	Rostock	Urban	high	371	149.6	CSG and non-photogrammetrist
1997 ObEx0.7.1	Oedekoven III	Suburb	high	525	**70.0**	Slider for height measurement
1998 ObEx0.8.2	Oedekoven - SD.	Suburb	medium	29	**41.0**	Automated form adaption
1998 ObEx0.8.7	Frankfurt II	Suburb	high	3907	**40.9**	Automated form adaption
1999 ObEx1.0	Oedekoven	Suburb	high	62	**20.3**	Copying and guided adaption alone

Table 1: Development of acquisition times and the relation to the the involved new functionality (Compl.:=complexity, Prim.:=# of primitives in the data set, Sec/P.:=seconds per primitive).

	ETH Zurich (Grün and Wang, 1998)	**University Bonn**	**University Stuttgart** (Brenner and Haala, 1998)
Input	Digital images	Digital Images	Laserscandata Rectangular groundplan(2D) Map data [+images]
Viewing	Stereo	Mono in multiple images	None (Automated) or Mono in laser data [editing]
Measurement	Point wise (sequence)	CSG-primitives	CSG-primitives
Automation	Roof part adjustment	Height determination, Parameter estimation	Height determination, Parameter estimation
Status	Commercially available	Development, projects	Development, projects
Editing	Needed and available	Needed and available	Needed and available
Accuracy	Like Photogrammetry	Like Photogrammetry	Height very high XY depending on resolution of laser data
Output	Polyhedral objects	CSG structure Polyhedral objects (ACIS)	CSG structure Polyhedral objects (ACIS)

Table 2: Some features of three current methods for building acquisition

4 CONCLUSIONS

The system for semi-automatic building extraction is used for a rapid acquisition of 3D information from multiple digital images. The operator is supported by a variety of tools, that automate specific parts of the measurements process. In case of failure the operator has several alternatives to react, but can at each stage go back to purely manual measurement to still perform the task. This we regard as a major essential feature of our approach. Except the reasonable assumption of having oriented image data available, we do not require other type of sensor data or additional ground or map information to perform the task, which is a second major strength. The third one is the independence from stereo, which would require special skills and special equipment. However, in cases of difficult interpretability stereo certainly has proofed advantages. By using multiple image information, we try to overcome that deficiency. With the described functions we can reach a performance of about 20 seconds per building primitive, which is fully comparable to currently used classical stereo photogrammetry. We believe in our philosophy of automation in combination with interaction. We have demonstrated how we can gradually increase performance. Our current interest is focused on getting feedback from external institutions, which use a version of our system on different image material. Diploma theses and exercises are running or are planned at several universities.

We have made good experience to adapt the software to new problems, or to integrate new modules. We do not focus right now on further increasing the speed, we rather concentrate to robustify the automated tools and to adapt and extend them to the problem of complex building structures in downtown areas and large scale imagery to reach similar acquisition times as for suburban areas.

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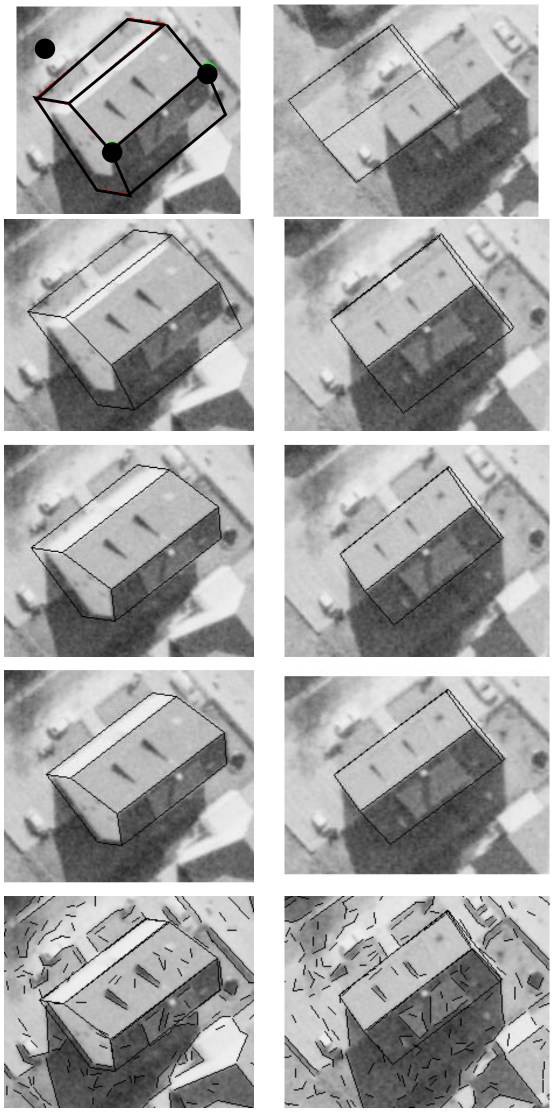

Figure 4: Example of measuring a saddleback-roof building using correlation and matching techniques based on image edges. **1st row:** Operator measures two gable points in the left image. Then a point on the ground nearby is selected. **2nd row:** The roof-top height is adjusted using image correlation. **3rd row:** The gutter width and height is determined by matching techniques. **4th row:** The ground height is determined using image correlation. **5th row:** Optional fine adjustment to further improve the result.

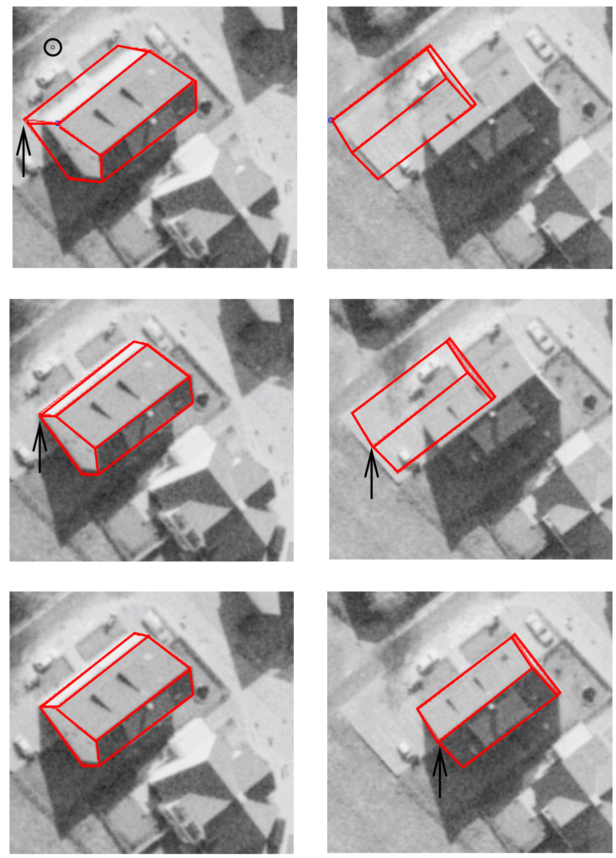

Figure 5: Measuring ground and roof-top heights. Left and right image are displayed. **1st row**: the model is fitted in the left image and a point close by (circle) is chosen to determine the ground height. **2nd row**: The ground height is adjusted, visible in the left image. The absolute height is not correct yet. **3rd row:** the model is fitted to the correct height in the right image by correlation of a roof-top point.

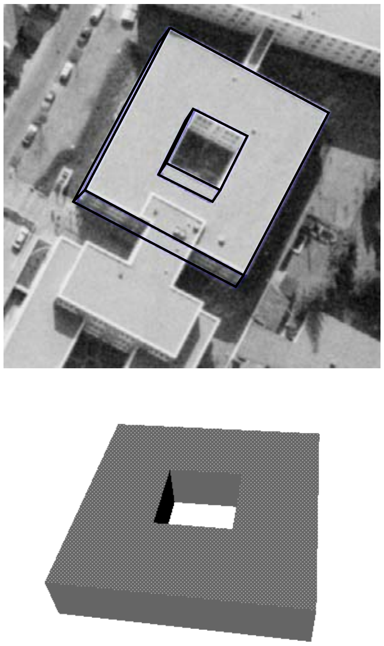

Figure 6: Modeling an inner yard by combining primitives with CSG operation DIFFERENCE. **Upper:** Two flat roof primitives and operation DIFFERENCE, **lower:** resulting 3D model

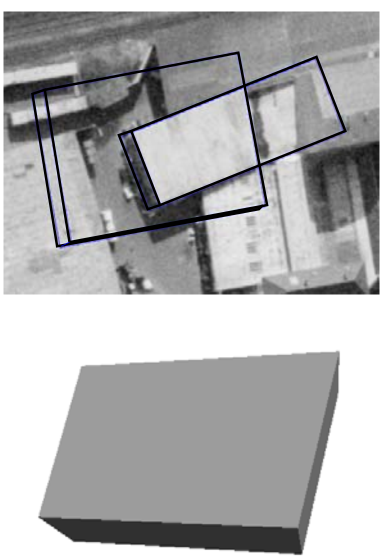

Figure 7: Modeling a non rectangular building complex by combining primitives by CSG operation INTERSECTION. **Upper:** Two flat roof primitives and operation INTERSECTION, **lower:** resulting 3D model.

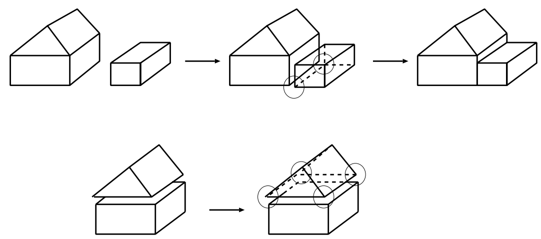

Figure 10: Gluing of a flat roof building to a saddleback roof buildings (upper row) and of a roof part to an underlying flat box (lower row).

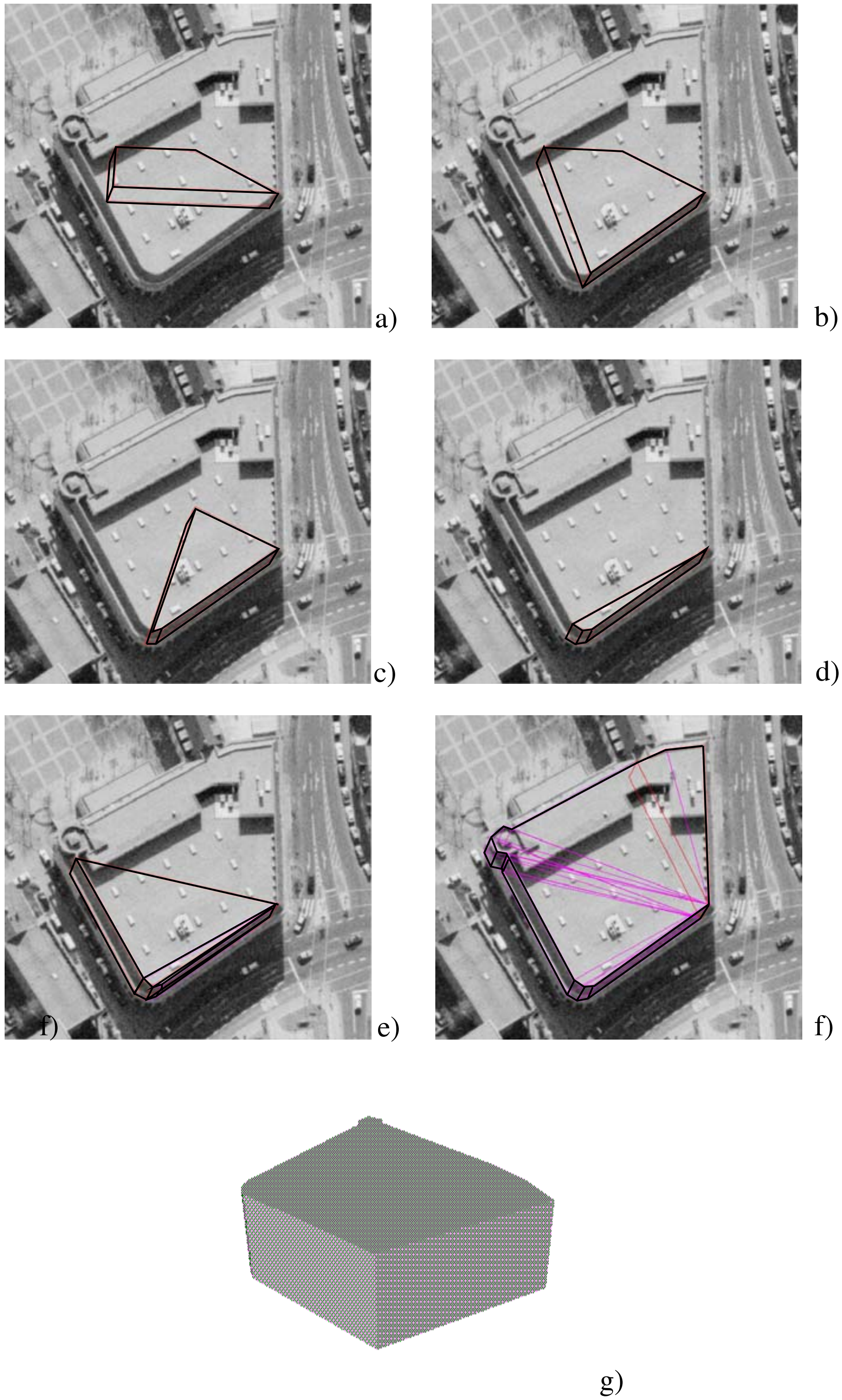

Figure 8: Modeling a polygonal object of constant height by generating a CSG tree (UNION-operation) of single four corner primitives. **a)-f)** shows the borders at the different stages in the left image and **g)** shows the resulting 3D-model (Note: the relative building height is not finally adjusted yet in this example).

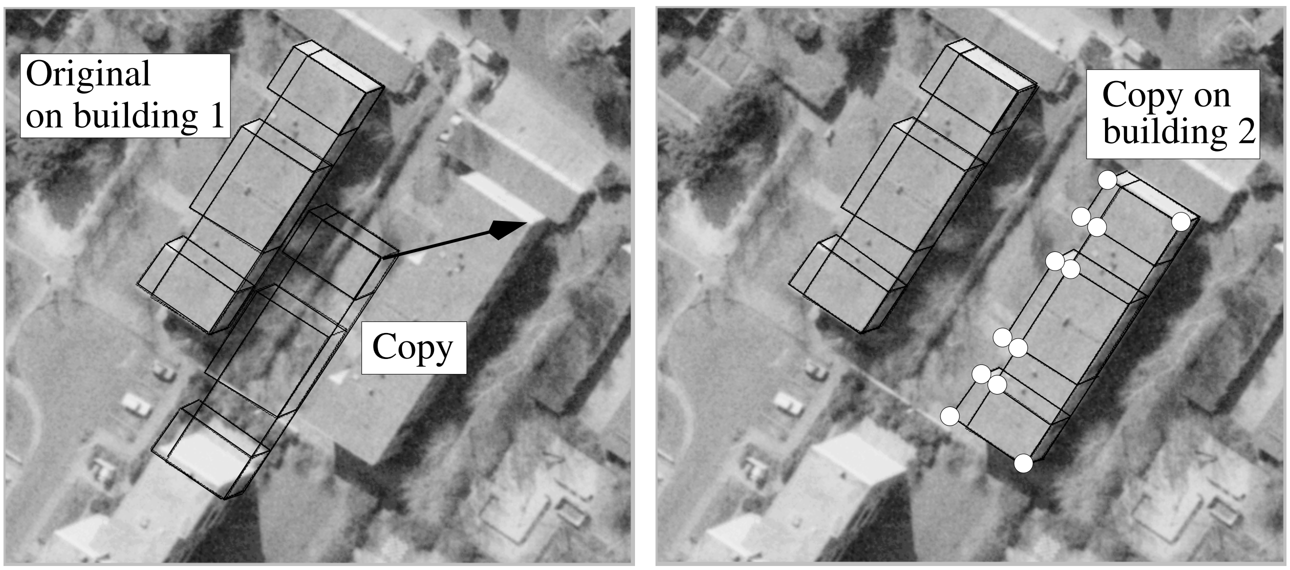

Figure 9: Copying CSG-trees. **Left:** One building (B_1) has been modeled. A copy of the complete CSG-tree is generated and has to be moved to the neigbouring building indicated by the arrow. **Right:** The second building is modeled by just translating the copy to the correct position. In this case no further operation was required as the rotation around the z-axis, all form parameters and the absolute height were the same as for the first building B_1). As an alternative 12 points would have been to be measured again (+ground) or four primitives would have to be combined like in the case of building B_1.