Towards Virtual Maps: On the Production of 3D City Models

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Introduction

In the area of high resolution digital surface model (DSM) generation, great advances have been made by the application of laser scanner systems. These systems have lead to a more economical data capture, but probably more important, to a more faithful reproduction of the object surface. Surface measurement within dense urban areas has become feasible, and even details like chimneys can be observed in the datasets. However, the direct use of dense range data poses problems in simulation and visualization performance and quality. The growing demand for medium and high quality city models as well as the obvious unability of traditional photogrammetric techniques to provide an economical solution has stimulated research into automatic and semi-automatic reconstruction methods.

Electro-magnetic or noise propagation simulations and visualizations for architectural planning have been classical examples for areas where 3D city models can be used. However, it becomes apparent that possible users might be in new application areas rather than in those classical fields. For example, it is an emerging theme to combine 3D city models with other information in order to faciliate trip planning for tourists. Also, the buildup of distributed city information systems, which allow access to up-to-date, historical and commercial 3D, 2D and scalar information using a mobile personal digital assistent (PDA) are a topic of growing interest. Those systems will have „point and click“ functionality where the user can query his PDA about information on the building in front of him. Systems for the efficient acquisition and update of 3D city models will play a crucial role in this context.

In this paper, the authors present an approach for the reconstruction of 3D city models from a DSM and ground plans from a GIS. The approach uses a two-stage system consisting of a fully automatic 3D reconstruction module and a semi-automatic editor which allows to manually refine the models. The result are 3D CAD models of the buildings. By an optional mapping step of terrestrial images onto the reconstructed facades, virtual city models can be generated.

Input: The Data Sources

Airborne laser scanning is a relatively new method for dense 3D point determination. In contrast to the classical image matching approach, this active technique provides DSM’s of high and homogeneous quality even in urban areas. For our test, we used laser data acquired by the TopoSys laser scanner with a point density of approximately one point per square meter. Figure 1 (left) shows part of the laser scanner DSM for one of our test scenes (city of Karlsruhe). A corresponding DSM obtained by the image matching program Match-T is shown on the right. In standard image matching, there is usually a tradeoff between a good reproduction of step edges and the elimination of matching errors, as controlled by some smoothing parameter. In most cases, laser DSM’s provide a better measurement at step edges. Nevertheless, it has to be noted that due to mixed point and interpolation effects, vertical building walls are still not strictly vertical in the data set and narrow streets do not reproduce very well. Also, laser scanners do have problems at surfaces with a high specular reflectivity or absorption like metal or slate roofs.

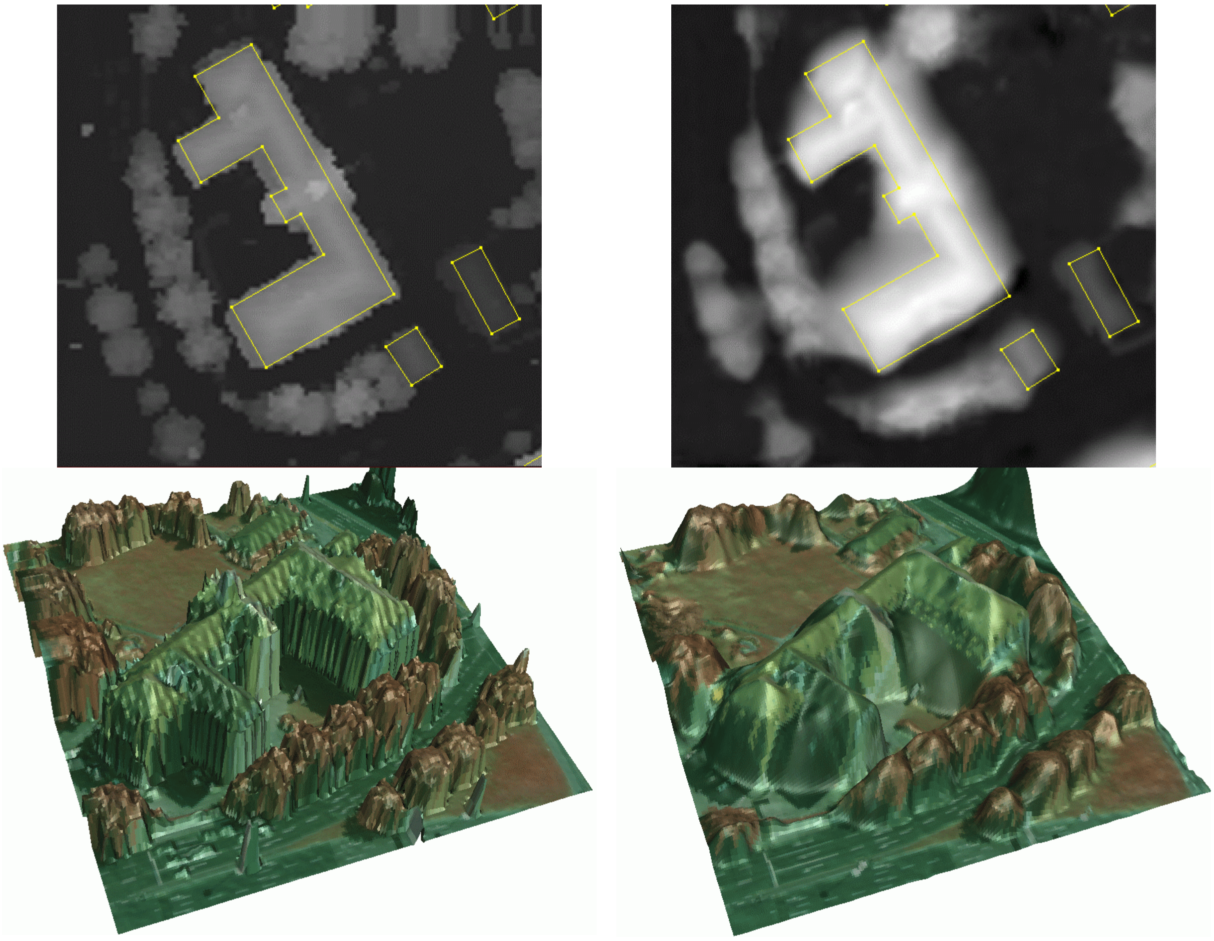

Figure 1: Part of Karlsruhe DSM obtained by laserscanning (left) and image matching (right) shown as gray value (top) and 3D visualization (bottom)

Thus, in our opinion it is a hard problem to extract reliably and exactly the boundaries of buildings from image matching or laser scanner data. Therefore, our approach uses digitized 2D ground plans as a second data source. They can be obtained either from existing GIS, or by manual extraction from maps or plans. In each case, the ground plans represent a certain amount of interpretation by the operator.

Figure 2 shows a DSM with overlaid ortho image of parts of Heidelberg. The DSM consists of a regularized 1m x 1m raster and covers an area of approximately 1 x 2 km^2. For our Heidelberg testsite, a total of 1600 ground plans were digitized from a German 1:5000 scale map.

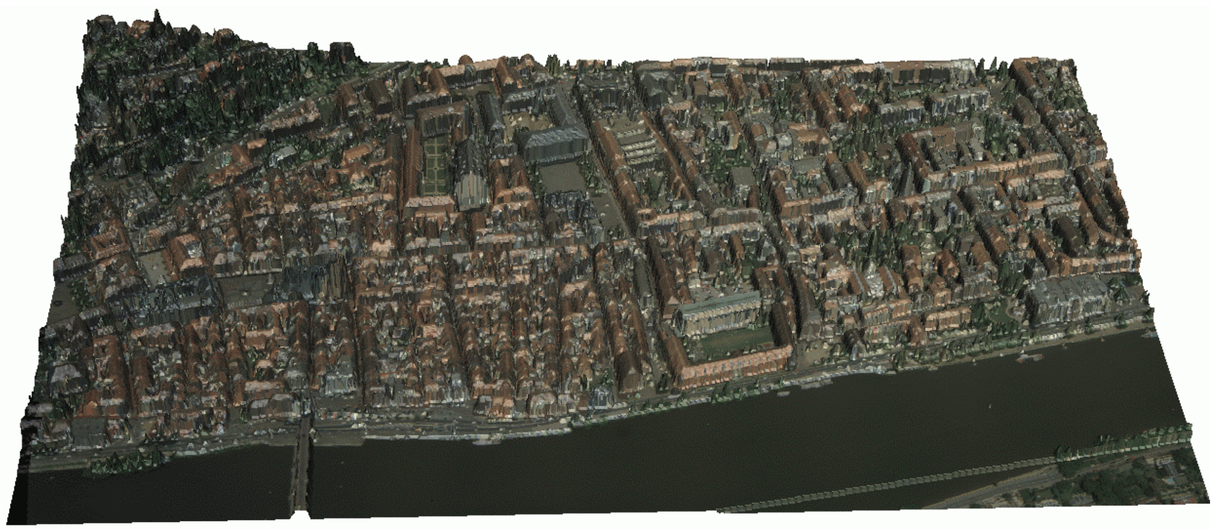

Figure 2: Heidelberg DSM with overlaid ortho image

Automatic Reconstruction

The problem for any model based reconstruction algorithm lies in the selection of the appropriate model. On the one hand, it should be general enough to represent real world objects in sufficient detail. On the other hand, it should be specific enough to constrain the solution in order to deal successfully with noise or outliers. In our case, we decided to transform the problem of reconstructing a complex building into the problem of reconstructing its basic units (primitives). Each primitive can be one of a fixed set of parametric models. This simplifies considerably the reconstruction process.

Figure 3 sketches the workflow of our reconstruction algorithm. Input data is on the left, output on the right and the flash icon marks the places where manual interaction can override automatically derived data.

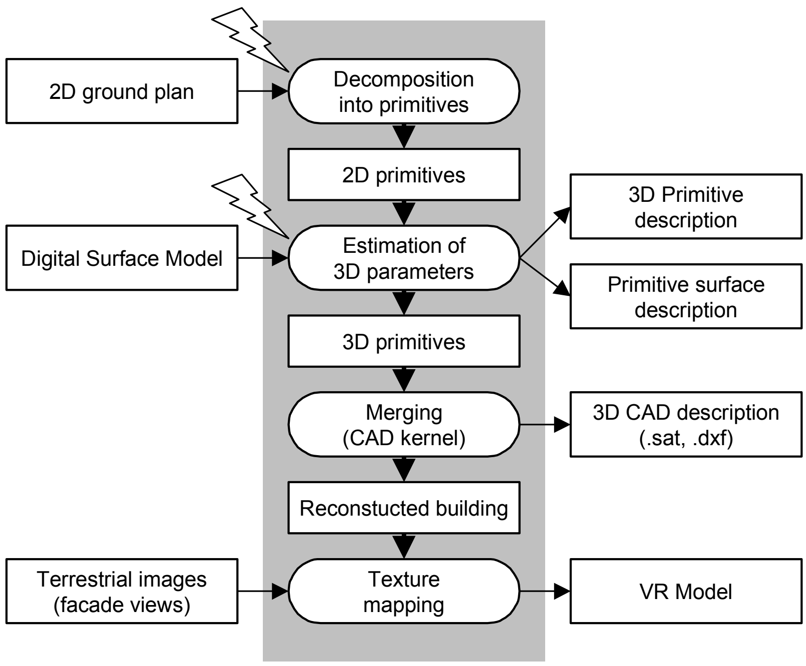

Fig. 3: Workflow for the automatic 3D building reconstruction

Processing starts by decomposing the ground plan polygon into 2D primitives (rectangles). Each 2D primitive is the footprint of a corresponding 3D primitive. The location, orientation, and size of the 2D primitive applies as well for the 3D primitive. What remains to be determined are the parameters of the roof, namely roof type (currently one of flat, gable and hip), height of the building and roof slope. A least squares estimation computes the best fit of the models to the given DSM. When several models are suitable, the one with the smallest residual is selected. After this step, the individually reconstructed primitives are overlapping 3D solids. They can be output in the form of either a list of solid descriptions or a list of planar faces. Most often it is desirable to find a building description without overlapping parts. As this is a standard Constructive Solid Geometry (CSG) problem, we use a CAD kernel to perform the necessary merging (Boolean union) operations. Finally, a non-overlapping building description is obtained, which can be exported and converted into different CAD formats.

Manual Refinement and Semi-Automatic Reconstruction

Since the decomposition into 2D primitives uses only ground plan information, features in the 3D geometry of the building can only be detected if there is a corresponding hint in the ground plan. The basic assumption here is that each ground plan polygon segment defines one wall and one planar roof surface. Hence, a bay or a small tower inside the building will not be reconstructed by the automatic algorithm.

For an effective visual control of the 3D reconstruction and to allow the manual refinement of building models, an editor was implemented. The tool allows to define, delete and modify 2D building primitives. 3D primitives are reconstructed instantly (using the same algorithms as those employed in the fully automatic reconstruction) when the user modifies the underlying 2D geometry.

We found it sometimes difficult for the operator to interpret a scene from a single data source like an ortho or stereo image. Thus, our editing tool supports the simultaneous display of 2D ground plans and primitives in an arbitrary number of images, like a scanned map, an ortho image or a greyvalue-coded DSM. Beside that, a 3D rendered display shows part of the DSM in the vicinity of the selected building and the current 3D building reconstruction.

Figure 4 shows a snapshot of the interactive editing tool with 2D and 3D display windows and the control panel. The 3D building primitives are shown in blue with the currently active primitive highlighted in red. The user can directly modify the 2D primitives in any window by mouse clicks and moves. Figure 5 shows an example of a building before and after manual editing. For this quite complex example, the automatic reconstruction solely based on the analysis of the ground plan (center image) is refined by manual editing of the 2D primitives (right image).

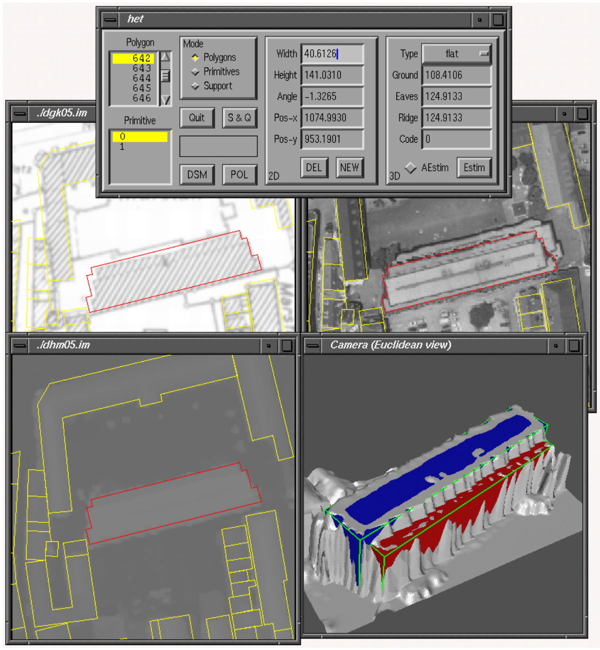

Figure 4: Interactive editing tool with map, ortho image, graycoded DSM and 3D view of DSM and reconstructed building.

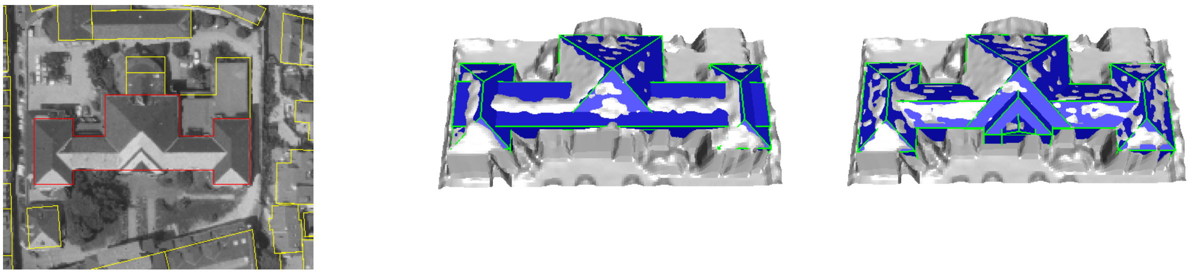

Figure 5: Ortho image and reconstruction before (left) and after (right) manual editing.

Applying texture

Using the described reconstruction scheme, effort and costs can be chosen depending on the application. When correct ground plans are available and all data is set up, a first 3D reconstruction is obtained fully automatically. This might be already sufficient for most of the buildings and many applications. In the next step details can be added to the buildings using the editing tool during the semi-automatic verification and modification. Compared to other systems, however, reconstructed buildings are already available – there is no need to start „from scratch“.

The final and most time-consuming step consists in adding texture maps to the building facades. Since real-world imagery embodies a representation of object detail, it can be a substitute for missing geometric details. To a certain degree, non-planar surfaces can be represented by texture mapped planar surfaces without degrading the impression of viewing a 3D scene.

We use terrestrial images obtained by an inexpensive still video color camera. The images are rectified and mapped onto the corresponding building facade. At least four tie points between the reconstructed facade and the terrestrial image have to be measured interactively. Nevertheless, this method proves to be much faster than the standard approach of architectural photogrammetry, since the building geometry is already available. Figure 6 shows some texture mapped scenes from the Karlsruhe data set.

Figure 6: Texture mapped scenes

Conclusion

Our approach for the reconstruction of 3D city models employs a DSM and 2D ground plans from a GIS. There are basically three different detail levels that can be generated: automatically obtained geometry, manually refined geometry, and texture mapped VR models. Those levels correspond to an increasing amount of editing and field work. In the future, we plan to incorporate more complex primitives and an enhancement of the ground plan decomposition algorithm. Also, we will investigate how the manual work which is up to now required for texture mapping can be reduced.

Figure 7: Automatically reconstructed buildings (city of Heidelberg) on top of DGK5 map.

Acknowledgements

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