Photogrammetric Data Capture and Calculation for 3D City Models

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ABSTRACT

The 2D building data from the public Automated Real Estate Map (ALK) serve as a suitable basis for photogrammetric data capture for construction of large-area 3D city models.
The following report provides an insight into the procedure for the measurement and calculation operations based primarily on the experience and requirements of the 3D city model in preparation for the state capitol of Stuttgart.
This is a semi-automatic process, whose photogrammetric variables are generated analytically or digitally in 2½D mode. Generation of the 3D model is accomplished exclusively with calculation programs in batch operation.
The result is a high quality, digital 3D wire screen model for the data levels, terrain shape, buildings, structures and traffic areas. The fully renderable 3D city model is available in DXF format as well as an object-structured ASCII file.

1. INTRODUCTION

Representation of the real world as always been one of the main tasks of photogrammetry. The present state-of-the-art allows utilization of the ease of three-dimensional photogrammetric data capture for generating spatial representation forms.
Many types of community planning assignments depend more than ever on a vivid basis of illustration.
Here the municipal buildings and structures are in the foreground in combination with the topography of the terrain.
Measurement and calculation methods matched to one another form the basis for "computer landscapes".
3D city models are particularly suitable for visualization of GIS data due to their vividness as a planning instrument. In addition to the interest of architects and city planners in 3D data, the possibilities for application range from simulation of environmental effects to computer animation and virtual city tours.
Various methods of data capture are available for generation of 3D city models:

Laser scanning method from airplanes
Photogrammetric method

Since the laser scanner method provides a large quantity of unstructured elements, it cannot be used optimally for achieving the processing results described below. The photogrammetric method is proven and provides exact and definite interpretation results.
A primary aspect in generating 3D city models is, on the one hand, the use of the public ALK data base (2D) as the basis for the building and structure model and, on the other hand, the availability of current aerial photographs.
Initially 3D-compatible basic systems such as AutoCAD or MicroStation are available for data storage. One of our tasks is to prepare the 3D city model specifically for the GIS of the principal.
Geographic information systems are generally conceived as 2D systems. In the near future they will also be available on the market as 3D systems for generating such items as computer landscapes or 3D city models (catch word CYBERCITY) using the GIS database. Photogrammetry is the ideal method of data capture for this purpose and will have to be adapted to this fact.
The advantage of this type of data capture is that the ALK building data can be superimposed on the aerial photo evaluation allowing an initial quality check immediately. This provides information on

whether the preparatory work of photographic flight, match-point determination and aerial triangulation fulfill the desired accuracy requirements. Moreover important conclusions can be made regarding updating of the ALK building database.
The use of the ALK data sets close limits for the photogrammeter, so that it is sometime necessary to generalize measurement of the roof lines or homogenize them with the ALK floor plan, to prevent distortion between the roof surfaces and the building floor plan. Evaluation of large scale pictures (e.g. 1 : 4 000) would not be practical for these reasons and work make interpretation of the roof surfaces unnecessarily difficult.

2. PHOTOGRAPHIC FLIGHT

For generation of a virtual 3D city model ("building block model" with scale of 1 : 1 000), we recommend having a separate flight made with a photograph scale range of 1 : 10 000-13 000 during the leaf-free period. Measurement of the roof surfaces, which will have to be generalized or homogenized in coordination with the building floor plan as a matter of course, can be realized well with a photograph scale of 1 : 10 000 to 1 : 13 000.
For the aerial photographs we use the gyro-stabilized, GPS supported camera Zeiss LMK 2000 15/23 with Kodak slide film SO-359.
Any black-and-white aerial photographs from the state surveying bureau in the scale range of 1 : 15-18 000 are to small-scale and therefore not suitable.
On the other hand, interpretation of the roof surfaces using larger photograph scales of 1 : 4 000, for example, is considerably more complicated and expensive due to the high details recognizable.

3. PHOTOGRAMMETRIC EVALUATIONS

The following input data is captured photogrammetrically:

3.1. Digital Height Model (DHM)

Semi-automatic measurement of a regular height grid; additional capture of broken lines such as slopes, walls, ramps as well as individual altitude points on crests and dips; capture of broken edges of structures with CAD-supported, analytical stereo evaluation systems.

3.2. Checking Existing Buildings

Checking the officially existing buildings at the time the aerial photographs are taken. Marking of new buildings; marking of buildings not longer present.

3.3. Capture of Roof Surfaces and Structures

Due to defined special roof shapes (BDA) the building and structure data is superimposed on the relevant roof points and lines measured in the aerial photograph for generation of the 3d roof surfaces. This also applies for measurement of broken edges on structures.
Here it must be noted that subordinate building ledges are not taken into consideration in the calculation.
This means that subordinate roof structures such as dormer windows, elevator shafts and staircases, light dome, etc. extending beyond the normal shape of the roof are eliminated.
All roof shapes are therefore generalized so that insignificant details are smoothed. There is a smooth transition from the building structure to the roof (i.e. without roof overhang). This can result in deformations between the roof shape and the floor plan, which are, however, left.

Round building structures such as barrel roofs, large tanks, chimneys, etc. have to be broken down into multiple surfaces (e.g. octagonal prisms).

Prominent, complicated buildings such as television towers, castles, churches, are represented so that they can be recognized as such on the monitor. However this is highly dependent on the floor plan detail in the ALK.

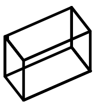
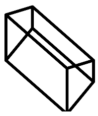
For calculation of the roof surfaces the ridge height or ridge line; eave height; buckling, arris and auxiliary lines are measured on the basis of the specified building floor plans. Capture of the roof surfaces is accomplished with CAD-supported, analytical stereo evaluation systems.

For evaluation only the number of elements are define in the measurement as required for calculation of the roof surfaces. For flat roofs, for example, only one roof point is required.

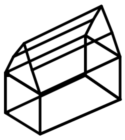
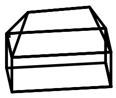
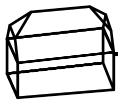
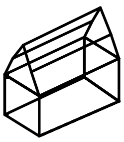
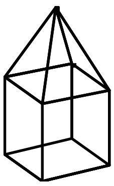
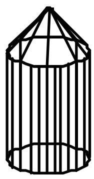
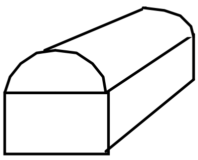
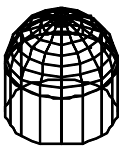
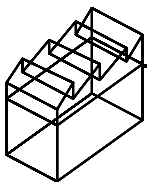
Basic Roof and Building Shapes

Classification according to definition of special roof shapes (BDA)
Basic drawings:

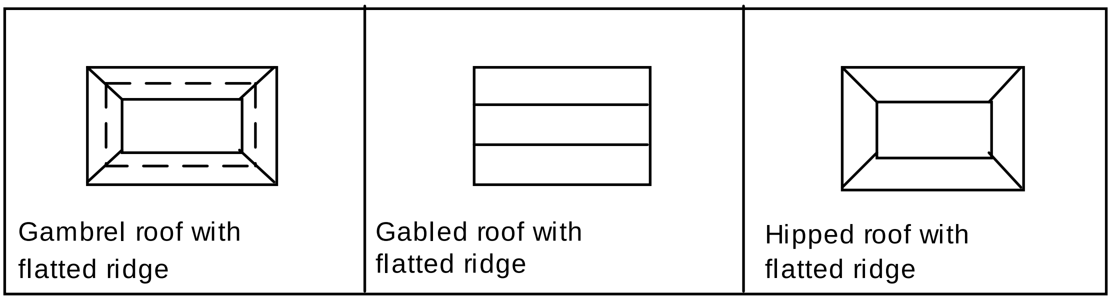
<u>Flat Shapes</u>

 Flat roof	 Lean-to roof

<u>Conventional Shapes</u>

 Gabled roof	 Hipped roof	 Half-hipped roof
 Gambrel roof	 Pyramidial roof	 Broach roof
 Barrel roof	 Dome-shaped roof	 Saw-toothed roof

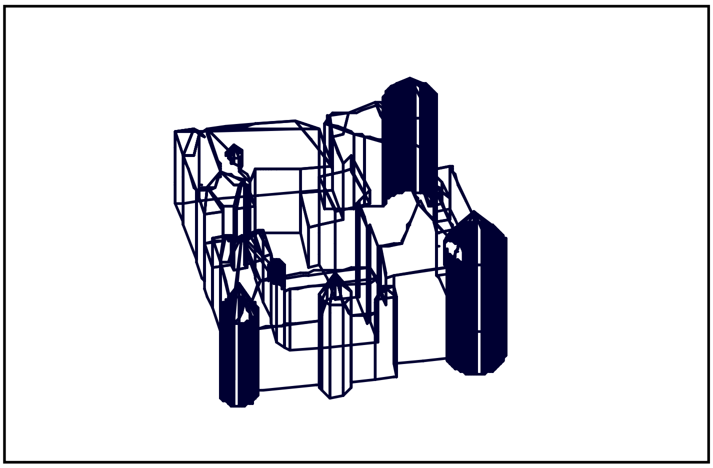
Other Shapes



Unconventional Shapes

Complicated building structure

Structures



4. MODEL CALCULATION

The following calculation steps are required for generation of the 3D building surfaces:

4.1. Calculation of the Digital Terrain Model (DGM)

The first step is to generate a digital terrain model as a surface-shaped, compacted triangular mesh grid from the DHM (height grid, broken lines, etc.).

4.2. Calculation of Building Surrounding Rings

In a further calculation step calculation of the building surrounding rings into the DGM is accomplished area for area using the data from the digitized city map. Here each reference point for the building surrounding ring is assigned the Z-coordinate (altitude above sea level) for the corresponding building height.

4.3. Calculation of Present Building Representatives

In addition to the building surrounding rings building representatives located inside the building are available as individual points. These are linked to an object number representing a combination of the street code and building number. These are also calculated into the terrain and filed in a separate data level. The building representative serves for later linkage to the item record.

4.4. Calculation of Building Structure

In a third calculation step the roof surfaces (BDA) are connected with the building surrounding rings calculated into the DGM. This results in the creation of vertical building surfaces.

4.5. Calculation of Structure

A possible option is to integrate bridge structures and street surfaces into the complete model. For bridge structures the height (specified passage height or standard cross-section) and width (abutment location) of passages (standardized) are taken into consideration including intersection with the DGM.

4.6. Checking the Calculation Results and Generating DXF Files

The calculated model is checked in each city area or processing area following each operation by visualization of the calculated wire grid model in the CAD system (3D). Here MicroStation and AutoCAD offer a variety of tools for visualization (rendering) and for interactive correction.
Another possibility for checking the quality is to superimpose the otho-pictures also present on the calculated wire grid model. Interactive corrections are always possible by comparison with the digital aerial photographic map.
Finally the calculation results are read out as DXF files in thematically categorized layers. Moreover practical ASCII structures associated with the building representatives can also be generated from the building surfaces.

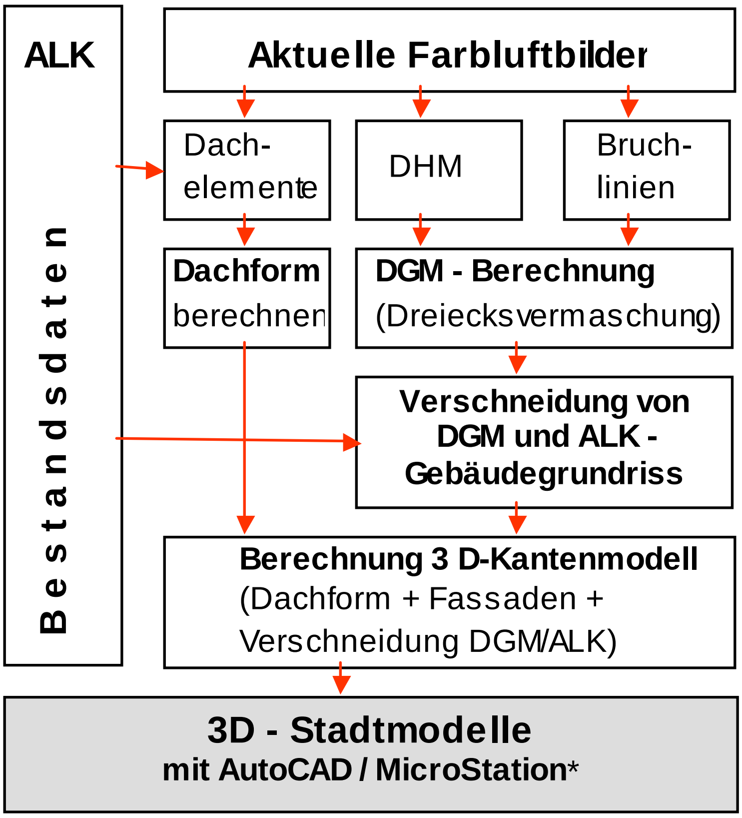


Figure 1: Procedure for photogrammetric measurement for CAD-conform 3D city and terrain model.

5. ACCURACIES

5.1. Scale 1 : 10 000

The accuracy of the individual point measurement at a scale of 1 : 10 000 (focal length 153 mm) is approx. ± 8 cm in the horizontal position and approx. ± 15 cm in height. All totaled the height accuracy of the roof surfaces is ± 0.3 m.

5.2. Scale 1 : 13 000

The accuracy of the individual point measurement at a scale of 1 : 13 000 (focal length 153 mm) is approx. ± 10 cm in the horizontal position and approx. ± 20 cm in height. All totaled the height accuracy of the roof surfaces is < ± 0.5 m.

6. DATA MODEL

The result is a high quality, digital 3D edge model (terrain, buildings, structures) in logical structure in the official position and height system and on the basis of building and structure data from the real estate register.
There is a smooth transition from the building structure to the roof (i.e. without roof overhang) and the building intersect with the terrain. The terrain is represented as a triangular mesh grid. The entire model is "renderable" (surface fill).
Integration of building representatives or ident. points for later linkage to item records is also possible.
The official building and structure floor plans present only in 2D to date are given a new quality by the processing described. The calculated wire grid model is provided area for area in a structured 3D format for GIS and CAD systems, standard in 3D-DXF format (three dimensional as "polyline" type for AutoCAD* or MicroStation*). The additional provision of the data as structured ASCII list allows and facilitates access to the various GIS configurations and therefore takes access to the individual buildings into consideration.

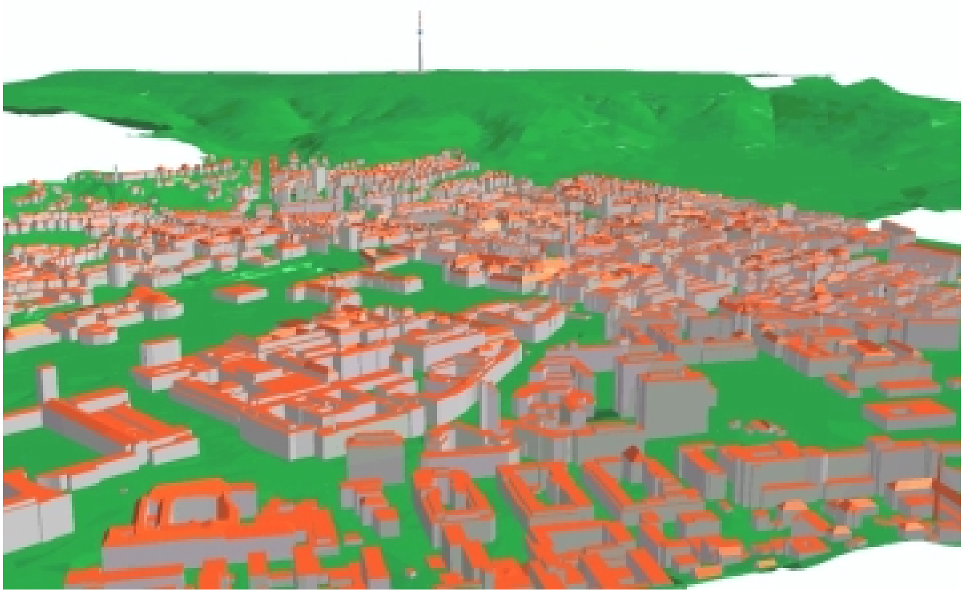


Figure 2: 3D view with permission of the City Surveying Office of the State Capital of Stuttgart.

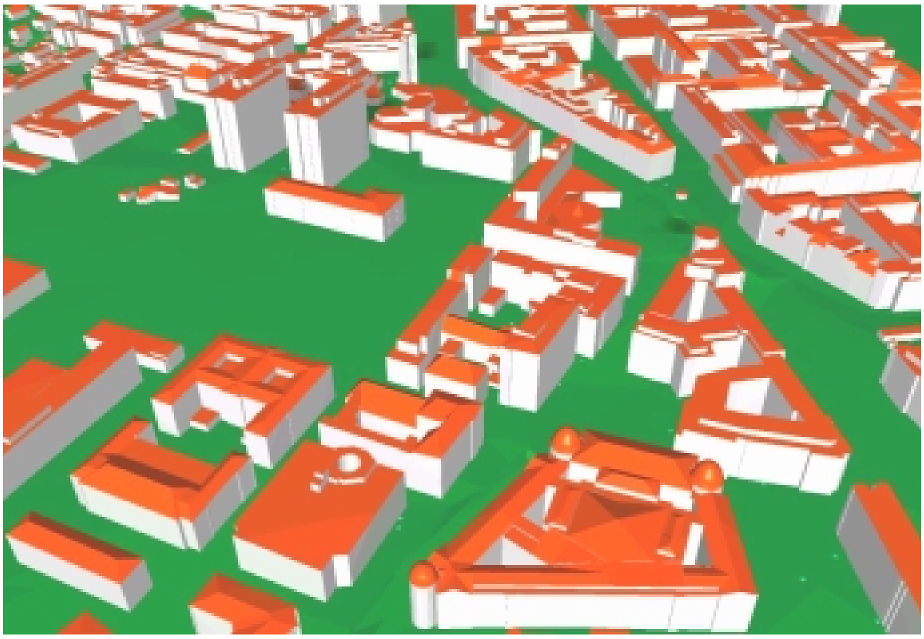


Figure 3: 3D view with permission of the City Surveying Office of the State Capital of Stuttgart.

Figure 4: Practical application example of a 3D study: Intersection of buildings and planned construction boundries.

7. SUMMARY OF POSSIBILITIES FOR USE

Municipal planning, e.g. for architects and city planners
Visualization of GIS data
Computer animation (e.g. virtual city tour or for advertising purposes)
Simulation of environmental effects (noise abatement, light studies, air circulation)
Mobile telephone studies and calculations
Checking buildings and structures in the ALK
Item data storage in GIS possible

8. CONCLUSION

This report has indicated a possibility for data capture and processing for generation of large area 3D city models. It is a semi-automatic solution based on photogrammetric methods using the official building floor plans in digital city maps.
The process is divided up into four steps. The first step includes the flight for obtaining the aerial photographs, match point processing and aero-triangulation (preparatory work). In the second step the DHM (regular altitude grid, broken lines, support walls, etc.) as well as relevant roof points and lines are measured using photogrammetric methods in coordination with the building floor plans (superimposition) according to predefined, special roof shapes (BDA).
In the third processing step the calculations are accomplished in batch mode area for area for roof shapes (roof surfaces with relevant structures), DGM, building surrounding rings in the DGM, side walls and representatives in the DGM.
The calculation results in a total of five DXF files for the levels: roof surfaces, DGM, wall, street areas and representatives.
Then the data is checked in the fourth step and, if necessary interactive corrections accomplished in 3D-compatible CAD systems.
The final result is accomplished by compilation of the five files to form a 3D wire grid model with closed polygonal surfaces. The complete model can be visualized and processed with CAD systems with suitable rendering tools.
Conversion of the 3D files into an ASCII format taking into consideration the building representatives allows access to the individual buildings, makes transition to the present GIS configurations possible and thereby also facilitates updating of the 3D data base.

9. REFERENCES

Bauer, W. (1997): Anforderungen an 3D-Stadtmodelle am Beispiel Stuttgart 21 [Requirements for 3D City Models using Stuttgart as an Example] in Fritsch/Hobbie, Photogrammetric Week '97, Wichmann-Verlag.

Gruen, A. (1997): Automation in Building Reconstruction in Fritsch/Hoobbie, Photogrammetric Week '97, Wichmann-Verlag.

Wolf, M. (1998): Photogrammetrische Datenerfassung und -verarbeitung zum Aufbau von Geoinformationssystemen [Photogrammetric Data Capture and Processing for Generation of Geographic Information Systems], Vermessungsingenieurtag [Surveying Engineer's Convention] '98, Hochschule für Technik Stuttgart [College of Technology, Stuttgart].

Bauer, W. and M. Wolf (1999): Erfahrungen und Perspektiven aus der flächendeckenden 3D-Gebäudeerfassung für Stuttgart - Teil 1: Grundlagenbereitstellung des Stadtmessungsamtes - Teil 2: Photogrammetrische Erfassung und Berechnung zum Aufbau des 3D-Stadtmodells, Technische Universität München, In: Münchner Fortbildungsseminar Geoinformationssysteme 1999.

* AutoCAD is a software product from the Autodesk Company
* MicroStation is a software product from the Bentley Company