PRACTICABLE PHOTOGRAMMETRY FOR 3D-GIS

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ABSTRACT

Encouragement for 3D-GIS comes from advances in technology and evolving user needs to cope with increasingly complex spatial analysis tasks. The demand for spatial information is most pressing in urban areas. The present paper elaborates on how current photogrammetric means can be used for 3D topographic mapping for municipal information systems. Aiming at comprehensive spatial 3D operation we rely on a data model that is based on 3D-FDS. Beside the basic issue of adequate data modelling and providing tools for analysis and visualization, efficient data acquisition is in fact the major challenge from the point of view of costs of creating a 3D-GIS. Even without automated information extraction from images, aerial and terrestrial photogrammetry offer solutions to both geometric object reconstruction and texture mapping. For testing the applicability of concepts and available tools we have built a prototype 3D-GIS. We also report our experiences with regard to the developed procedures and make suggestions for further development of photogrammetric means.

1. INTRODUCTION

3D-GIS is receiving increasing interest in R&D circles with possible applications in disparate fields. Being concerned here with the possible contribution of photogrammetry to 3D-GIS, our interest is not on spatial modelling of sub-surface phenomena nor on global environmental change, but exclusively on topographic objects. These are objects with discernible boundaries such as buildings, streets, man holes, the ground surface--objects traditionally subject to surface mapping. Three-dimensional (3D) refers to three spatial reference dimensions and not to 2D plus a time dimension.

The demand for spatial information is most pressing in urban areas. In the USA 75% of the population already lives in urban areas. It is predicted that at the turn of the millennium almost 50% of the world's population will live in cities. Urban planning and management of such enormous conglomerates becomes a rapidly growing problem. Prevailing initiatives to satisfy the demands for spatial information are the establishment of 3D-CAD models and 2D-GISs; the first supporting (architectural) design issues and the latter, municipal management. Designing, manipulating and graphically presenting 3D objects can conveniently be done by commercially available CAD systems. On the other hand, inventories, the analysis of spatial relationships and association with a multitude of thematic properties, are available in GIS. 3D-CAD models, also referred to as 3D city models, have already been built and used on a project basis (see, *eg*, Rinner, 1993; Grün et al, 1993; Gruber et al, 1995; Ranzinger et Lorber, 1995). They offer photo realistic views, animation, and interactive 'walk through' when linked up with virtual reality browsers. They do not supply analytic analysis of relationships between objects. Even current GISs fall short in furnishing 3D topology, and visualization of aspects of an urban scene by 2D line maps is unsatisfactory in many cases.

A 3D-GIS that is also capable of feeding 3D-CAD models can overcome the above indicated problems. To this end we need a data model that can cope with geometry, topology, and semantics. Chapter 2 identifies requirements for an urban 3D-GIS and describes the spatial data model based on the formal data structure (FDS; Molenaar, 1992).

One of the big challenges in 3D-GIS is efficient data acquisition. A great deal of information about objects with discernible boundaries can be extracted from images, specifically from stereoscopic images when 3D objects are the matter of concern. By employing photogrammetry we can take full advantage of its 3D measuring capabilities as well as the possibility of image mapping for photo true visualization. In chapter 3 we describe procedures readily applicable by building on commercially available photogrammetric tools. Since our interest is directed at production-oriented environments, we shall not review progress made in (semi-)automated building and road extraction, but will elaborate on manual (point) photogrammetry, considering both analytical and digital plotters. Leaving object recognition to the human interpreter, we concentrate on object reconstruction.

For testing the applicability of concepts and available tools we have built a prototype 3D-GIS. Chapter 4 provides an outline of its components and presents results from pilot studies which have been conducted. At this stage the emphasis of our studies is on geometry, leaving aside semantic modelling which is very much dependent on the specific application context of the GIS.

Based on the problems encountered in the pilot studies, the paper concludes with design considerations for future digital plotters which should offer higher 3D productivity.

2. 3D-GIS

2.1 Requirements

A 3D municipal information system should support civic activities ranging from administration to planning and construction for city (re)development, planning and management of utilities, security assurance, environmental management, and conservation. The promise of 3D-GIS is better accessible inventories, extended spatial analysis, refined simulations, and more appealing visualization than either 'flat' GISs or solitary CAD models can grant. Moreover, a 3D-GIS could also support automation of photogrammetric object reconstruction by providing information for model based image analysis. 3D analysis capabilities could also be exploited to efficiently plan and conduct field completion (see Felus et al, 1996).

This broad spectrum of application presents multifarious requirements for the urban 3D-GIS these include:

- provision of means to construct the digital model representing geometric and semantic properties of objects from various inputs and handling implied uncertainty
- integrity and maintainability of the database
- support of spatial analysis in different user contexts, including basic operations such as:
  - measure spatial extensions of objects (volume, surface area, line length)
  - answer topologic queries (pipe passing through the building?)
  - search and retrieve objects of certain properties
  - zoning, route optimization, lighting studies, etc
- support of simulations (*eg*, environmental impact analyses) and design (virtual updating of the existing situation by designed objects)
- effective visualization (perspective and orthogonal views, user (interactively) defined viewing direction, viewing point and stretch, photo realistic computer graphics and photo true pictures)
- promotion of different abstraction levels (multi-resolution)

A discussion of application areas of an urban GIS and requirements for its 3D model can be found, *eg*, in (Förstner et Pallaske, 1993). Pilouk (1996b) gives an overview of possible system architectures.

2.2 Data Model

The analysis of current GIS and CAD capabilities and software tools offered (see Bric et al, 1994) let us to decide to first look for rigorous spatial concepts for data modelling and on such a solid basis, see which available tools can be utilized and how. Focusing on urban scenes and considering the above requirements, we have selected a vector data model based on Molenaar's FDS.

The comprehensive 3D data model comprises geometric and semantic description of objects and allows for the analysis of 3D topology. It can be handled by a single DBMS. It is downward compatible with 2D-FDS so that data from existing GISs can be incorporated after being converted to this structure. It follows a 3D boundary representation because of the desired visualization capabilities. Photogrammetry offers accurate and economic techniques for the acquisition of vector data on urban topographic objects and provides for the input for mapping photo textures onto surfaces of objects. These raster data can be integrated into the vector model. Since we are mainly interested in object reconstruction, we can limit our review of FDS to the representation of geometry without elaborating on the modelling of semantics.

The 3D-FDS groups objects to classes in a thematic sense and distinguishes four types of objects according to geometry: point, line, surface, and body object (see figure 1). The representation of geometry aims at separating its three aspects: topology, shape and size, and position. Positional information is contained in the geometric primitive *node* with its x,y,z coordinates. The one-dimensional geometric primitive is *arc*. Arcs constitute line objects and boundaries of faces. *Faces* are two-dimensional primitives, they constitute surface objects and boundaries of bodies. Line objects, surface objects, and solid objects (bodies) have shape and size. To avoid ambiguity in the data model, arcs that constitute the boundary of a face, must be relatively oriented; the auxiliary geometric primitive *edge* is introduced for this purpose. Hence, *left* and *right* body to a face can be defined. The topologic relationships between the objects are defined through the geometric primitives and the links between them which are shown in figure 1. This diagram, together with a set of conventions, represents the basic data model. The conventions are rules that must be observed when structuring data; *eg*, faces must not intersect or touch, an arc cannot intersect a face, line objects have no branches, etc. When introducing the conventions that arcs are straight lines and faces are planes, they would not need any shape parameters. The data model as shown in figure 1 supports the handling of a large variety of queries and can be extended to build composite objects (see Bric et al, 1994). Moreover, it can be upgraded to structurally integrate a digital terrain relief model (DTM), see (Pilouk et Tempfli, 1994).

The 3D-FDS can be seen as an extension of the edge based boundary representation used in solid modelling. Since any face can also be part of a surface object, surfaces of solid objects such as building facades and roofs can be attributed textures. These can be synthetic ones from a material library for *photo realistic* visualization (near photographic quality) and/or rectified photographs for *photo true* (photographic quality) visualization. Decomposition of solid objects into boundary primitives serves both the analysis of topology and ray tracing.

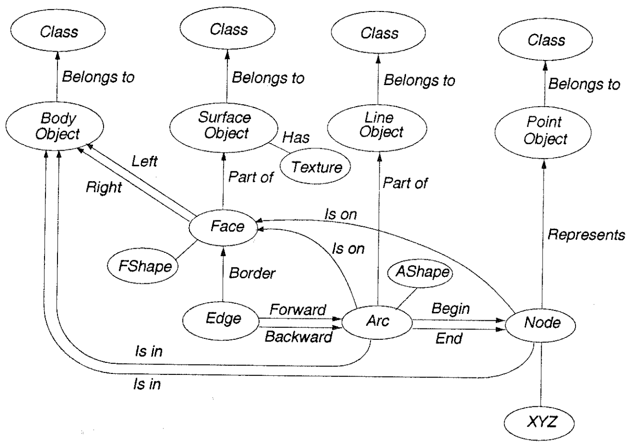


Figure 1 FDS offering 3D topology.

The 3D-FDS is upward compatible with a more universal data model, the simplicial network data model (see Pilouk 1996a). This model can also handle objects with indiscernible boundaries and facilitates spatial interpolation. Such a model is needed for integrated analysis and simulations as required, *eg*, for environmental studies.

3. PHOTOGRAMMETRY

3.1 Data Sources

Data acquisition is one of the major bottlenecks in building and maintaining an urban 3D-GIS. Cost effective systems are only likely if existing data are incorporated, different data sources (existing 2D municipal information systems, cadastre, aerial and terrestrial photogrammetry, GPS and other ground surveys) are used, automatic 3D model construction from disparate data sets is accomplished, and if progress is made in automating information extraction from images.

Photogrammetry tenders attractive means for 3D data acquisition, specifically in urban areas. Aerial photogrammetry

- is economic for surveying large areas,
- is flexible with respect to the level of detail and accuracy with the potential of very high accuracy of object reconstruction,
- can attain a high level of completeness,
- does not pose problems related to safety in measuring urban objects,
- allows for a timely survey,
- grants convenient verification and interactive database updating by superimposing vector data on the stereomodel,
- offers the additional benefit of an image archive and the possibility of photo texture mapping.

Nevertheless, occlusions cannot completely be prevented in densely built up areas, even with a good choice of survey camera and appropriate flight planning. Moreover, standard aerial photographs will not disclose sufficient detail for fancy image mapping of facades. Hence (field) completion is required, be it through airborne oblique and small format photographs, terrestrial photographs on photo-CD (Höhle, 1995), digital images from a 3 line CCD camera (Maresch, 1996), panoramic images from a fish-eye lens (FRANK, 1993), video, metric terrestrial photographs or ground surveying for detailed reconstruction of facades. The possibility of texture mapping instead of surveying facade detail offers cost effective information production, comparable to producing photomaps instead of line maps in traditional topographic mapping. For many applications a visual impression of facade and roof detail suffices. This does not hold, *eg*, for 3D models for routing of overhead utility lines where the relief of facades and roofs must be represented in 3D geometry, sometimes with high accuracy (see Baucic, 1995).

Focusing now on aerial photogrammetry, it can produce 3D vector data of topographic objects, ground elevation data (thus DTM), and photo textures--especially for roofs and terrain, and when colour photographs are available.

3.2 Tools and Procedures

3.2.1 Geometry

Measuring by photogrammetry always has been done in 3D, but for a 3D description of topographic objects instead of a 2D map as a result, we explicitly need all faces, *eg*, of a house, its roof facets, its walls, its footprint, and these elements in terms of coordinates and topology. This implies considerably more work in measuring and structuring data than traditional map compilation. Manual data acquisition, therefore, must be designed so that only a minimum number of points are measured and that the subsequent model construction (*ie*, object reconstruction and structuring according to FDS, thus creating the 3D database) can be done automatically. This aim can largely be achieved by defining an adequate coding system and a strict digitizing procedure (see Wang, 1994). Extracting features and coding them in such a way that 3D objects can be assembled, can be accomplished by using standard photogrammetric digitizing software (*eg*, CADMAP, KORK, Microstation). Algorithmic assemblage of objects from the coded point measurements, structuring the data to FDS and checking the consistency requires development of software. If, however, model construction does not need to result in an FDS database, then it could be programmed (or done manually) in a commercial CAD package such as AutoCAD or Microstation.

Unless flat terrain and only simple objects are involved, final quality control and validation must be done visually, preferably on-line with adequate 3D superimposition. Feeding back data from the FDS database to the digitizing software (*eg,* via DXF) requires again development of a data interface. Such 3D topographic mapping by digitizing features of man made objects in stereomodels, with superimposition of already available vector data, can be done on analytical plotters (AP) and digital plotters (DP) (the latter also being referred to as digital photogrammetric workstations). Recent project work using an AP and CAD software for model construction was also reported in (Littleworth et Chandler, 1995), presenting fine examples and a market perspective for such products.

For the collection of ground elevation data, one may consider automatic DTM generation, but this will not be expedient when working on large scale photographs of densely built up areas, since most current image matching algorithms cannot adequately deal with occlusions and multi-valued surfaces. Verifying and manually correcting a DTM obtained from image matching may even take longer than direct manual elevation measurement. Both APs and DPs are suited for manual and semi-automatic DTM data collection.

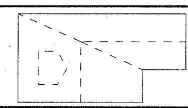
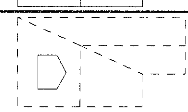
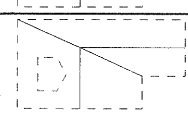
A further problem arises when going to detailed terrain representations, namely, the definition of the ground surface. For example, are stairs part of the ground surface? In case of a canal or a swimming pool shall we take the water surface? What to do with a heap of sand next to an artificial lake? Obviously, object definition according to application context must be settled prior to photogrammetric work.

The coding system will depend on the object definition, and together with the digitizing convention (*eg,* counter clockwise line strings), controls object assemblage. Actual coding must be tailored to the capabilities of the digitizing software. For object reconstruction we can distinguish two basic categories of objects: (a) surface, line, and point objects coinciding with the ground surface (*eg,* parcels, sport fields, parks, streets, rails, drainage, man holes) and (b) objects 'sticking out' (*ie,* either having significant vertical extension or dangling above ground, *eg,* buildings, walls, poles, fly overs, power lines). Collecting data for the first category should be combined with DTM generation. For the second category, houses specifically (with vertical walls and non-overhanging roofs), it is sufficient to measure the top when using aerial photographs and then generate the footprint and the walls by intersection with the DTM.

Table 1 shows a few examples of detail to be measured and figure 2 illustrates the reconstruction steps of a house with vertical walls.

Not all roof outlines are edges of walls that rest on the ground (see B1 versus B2). Coding must be sufficiently detailed to cope with different spatial relationships. The required level of detail determines what needs to be measured as a minimum. Digitizing and coding of surface, line, and point objects of the first category is straightforward. Vertical surface and line objects (*eg,* fences and poles) are difficult to digitize unless the photoscale is very large. Their height often has to be obtained by terrestrial measurements. Interpretation training and knowledge of the human operator about the subsequent structuring process are prerequisites for efficient manual data collection.

Table 1 Examples of elementary features and coding

Type	Code	Description/Example	Purpose	Graphics
Body feature	B1	Roof outline	To construct the body by plane sweep vertically to intersect with DTM	
Body feature	B2	Roof outline	Intersect with body	
Surface feature	S1	Roof facet boundaries (ridge and drainage)	Replace the roof outline after obtaining the body	
Surface feature	S2	boundary of tennis court, street edge	To be part of ground surface	
Line feature	L1	railway	To be part of ground surface	
Line feature	L2	lamp-post	To be completed by providing height	
Point feature	P1	Location of a tree, man hole	To be part of ground surface	

Topologic relationships are recorded through data structuring (therefore sometimes referred to as building topology). This in fact goes hand in hand with reconstructing the objects. To reconstruct a house, we need the ground surface defined by a TIN and the outline of the roof (see figure 2b). Projecting the roof yields the footprint which must be incorporated in the TIN by local retriangulation (see figure 2c). This way an integrated representation of terrain relief and other topographic objects is assured; the topologic relationships between ground surface and solid man made objects is established and maintained in the FDS database.

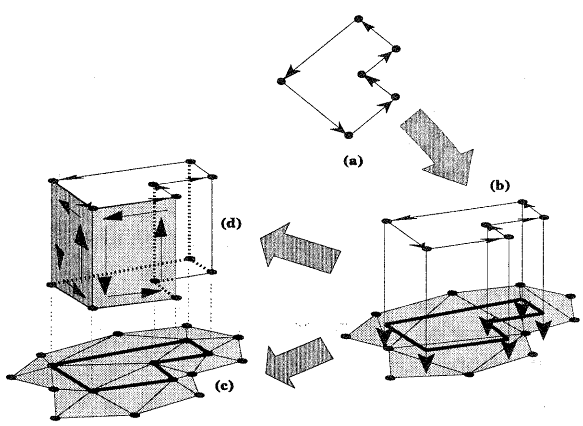


Figure 2 Steps of data structuring for 3D FDS.

Figure 2d indicates that the faces defining the walls are oriented to serve 3D visualization which requires that the normal vector of each visible face of a solid object should point toward the outside of the body.

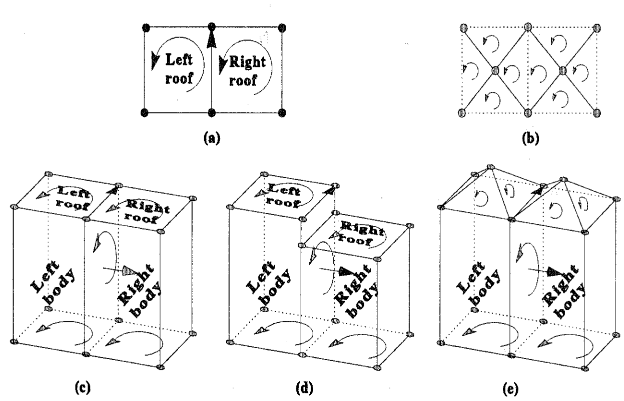


Figure 3 (a) Outline of two adjacent roofs, (b) details of the roof, (c) two adjacent flat roofs with the same elevation, (d) similar to (c) but different elevation, (e) replacing the outline of the roofs by their facets after reconstructing the main geometry.

Not all topologic relationships, however, which are shown in figure 1 (*eg*, a node in a body), can be established at this stage, because of the lack of information from photogrammetric data collection. In some cases adjacency can directly be inherited from 2D topology (see figure 3a and 3c), but in others (see figure 3d) manual intervention becomes necessary. This matter still needs further investigation.

Dealing with occlusions is a bigger problem in 3D than 2D topographic mapping. The chances of attaining a tolerable algorithmic completion of invisible edges are much less. A remedy can be sought in acquiring photography for 3D mapping with larger than conventional overlaps, and providing better facilities for multi-image access. In a photo flight with generous overlap it is more likely that a point hidden in one stereomodel is visible in other images. On a DP, either local image matching with a 'third party' could be attempted, or quickly swapping stereomodels to one where the once hidden point can be observed. Despite of procedural refinements of aerial photogrammetry, complete geometric reconstruction of the urban scene will generally not be possible. Since position will usually be defined in a national coordinate system, all field completion work can unambiguously be linked to the data collected photogrammetrically.

A DXF interface between the FDS database and the photogrammetric subsystem for superimposition and editing is also convenient for linking up to commercial rendering software such as 3D-Studio or virtual reality software accepting VRML files such as the 3D viewer WIRL on Internet.

3.2.2 Semantics and Texture

Digitizing features in a stereomodel is not done without interpretation. The semantic information extracted by interpretation can easily be encoded by extending the codes used for object reconstruction. In model construction the codes must be translated to class labels and thematic attributes for the FDS database.

A bigger problem is extracting photo textures, geometrically and radiometrically rectifying the image segments and storing them in the FDS database. Once the roofs, walls, football fields, etc are geometrically determined, the image coordinates of the boundary polygons are readily available on any photogrammetric plotter. On a DP it is then conceptually not difficult to 'cut out' the corresponding image segment and geometrically rectify it to the face. Before archiving such image segments, it is desirable to retouch those images that have alien texture (*eg*, tree on a facade). The problem of occlusions is even more aggravating for image mapping than it is for extracting vector data. Automatic retouching is not that trivial, but manual image manipulation is offered by commercial programmes like PHOTOSHOP, PHOTOSTYLER, etc. Another desired processing step is radiometric homogenization in order to reduce effects of different lighting conditions (see Gruber et al, 1995).

4. PILOT PROJECT

For studying the applicability of the developed concepts and tools, we have first limited ourselves to the modelling of buildings, an important component of an urban scene. We have built a rudimentary 3D-GIS and report here on the components, the data flow and the bottlenecks encountered.

4.1 TREVIS

The data model presented in figure 1 can be translated into different kinds of database structures. The relational and object oriented structures are the most interesting ones. For practical reasons we have chosen for our proof-of-concept demonstrator the relational structure (see figure 4) and dBASE IV for database management.

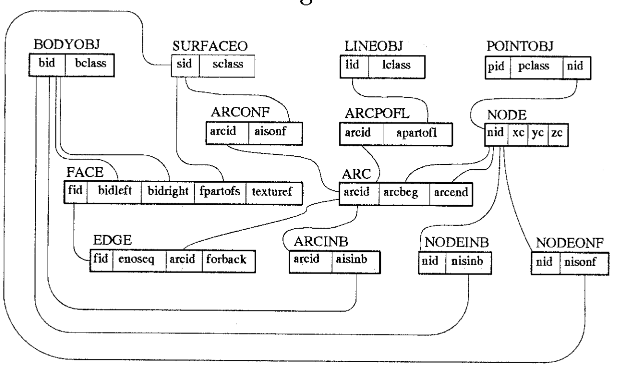


Figure 4 Relational data structure of 3D FDS.

Our experimental 3D vector GIS (TREVIS) is built in a PC environment with a Zeiss C120 analytical plotter and a Matra Traster T10 digital plotter connected by Ethernet. In-house software development was needed for (1) reconstructing solid objects from the digitized features and structuring the data according to FDS, and (2) interactive visualization of 3D objects. For system testing purposes, at least, it is necessary to have tools to inspect an object from all sides and with different enlargements. Stereoscopically presenting objects in perspective wireframe views using the anaglyph principle suffices for this purpose. The graphics are produced directly from the dBASE files. We can, therefore, use this tools to also visualize query results. Moreover, a 3D cursor (like a photogrammetric floating mark) allows the user to move around in the anaglyph stereomodel and snap to the nearest node or to the middle of the nearest arc. The obtained node respectively arc identifier can readily be used as input to a query. This computer graphics tool can also be used for interactive verification and editing of the constructed model for applications where only the spatial integrity is important and the spatial accuracy relaxed. For database updating purposes and demanding accuracy requirements, however, sophisticated 3D visualization and its superimposition with the photogrammetric model are highly desirable.

We have tested various queries about topologic relationships among 3D topographic objects with TREVIS, *eg,* neighbourhood, adjacency and inclusion. The results obtained were summarized in (Bric et al, 1994). Here, therefore, we shall concentrate on photogrammetric data collection, model construction, and visualization.

4.2 Test ITC

We had selected two test sites. The first one was an open urban area with undulated terrain in Switzerland and a photoscale 1:5400. The second area was around the ITC building being covered by one stereomodel of 1:2200 scale photography. We digitized features of buildings on the Zeiss C120 with KORK and on the T10 with DEMETER. Our interest, in the pilot study was on finding the best strategy for collecting, structuring and checking data of buildings (see Wang, 1994). The procedures used on both systems were very similar. Although the T10 offers automatic DTM generation, we did not apply it for the ITC model. The terrain being pretty flat, it was certainly quicker to measure a few spot heights along the streets and open areas. The only advantage of the DP in feature extraction experienced, was the stereosuperimposition which we do not have on the C120. Our curiosity, however, with the newer system let us to continue on the DP; the stereosuperimposition was not the reason.

The production steps using the T10 were:
- define objects of interest (buildings, streets, ground surface)
- define level of detail (block level: global roof structure, vertical walls)
- design codes (see table 1) within capabilities of DEMETER
- digitize roof features and street edges with DEMETER and measure spot heights of terrain relief
- export coded points and line strings in DXF
- run model construction software
- interactively view reconstructed objects by TREVIS software
- import nodes and arcs from FDS via DXF in DEMETER for superimposition
- import DXF file in 3D-Studio for ray tracing and generating attractive pictures
- generate VRML file from the DXF file using shareware on Internet
- use WIRL for 'walk through'

Figure 5 shows a screen print of the interactive visualization of our test site 'old ITC and its surroundings' by the VRML viewer WIRL. Figure 6 gives an example of a near realistic visualization of a designed object, the new ITC building, which was produced by in-house developed software. By now it would be possible to replace the facades of this very complex building (its model was constructed from 2D architectural plans) with photo true texture, since the real world building construction has just been finished this year. Meanwhile we also have developed a direct FDS - VRML translator, but have not experimented with including texture mapping yet.

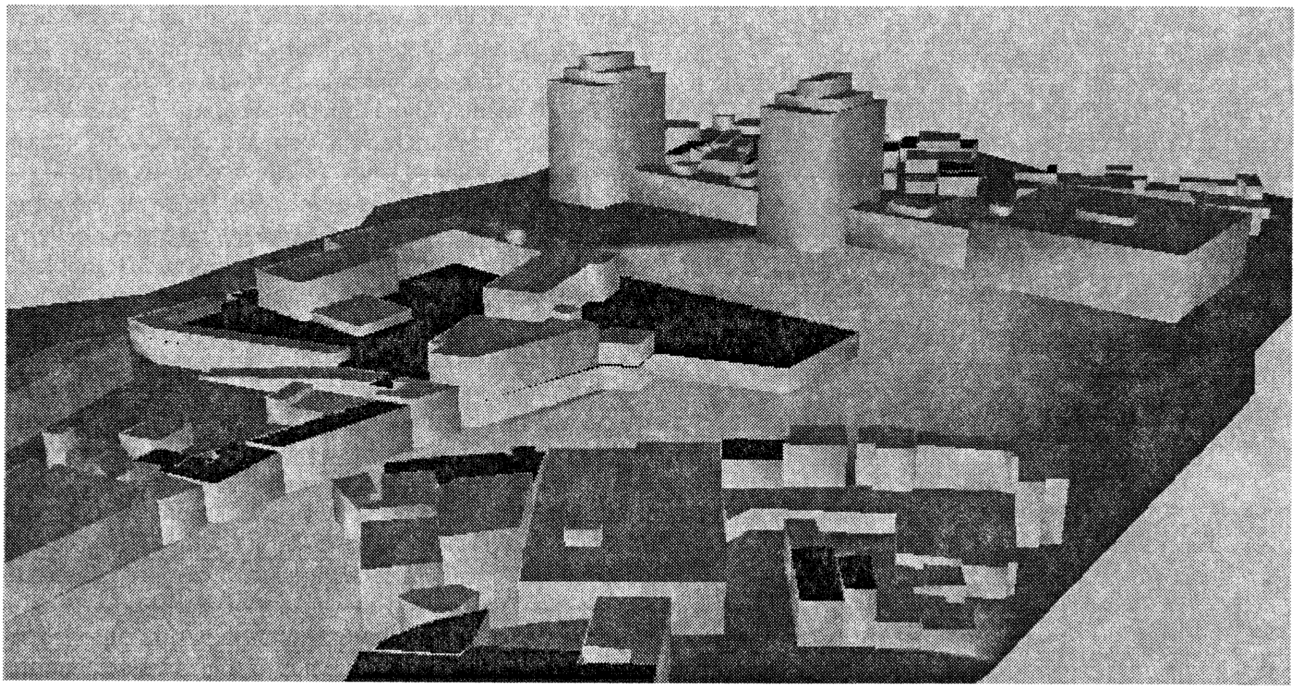


Figure 5 a The old ITC and its surrounding.

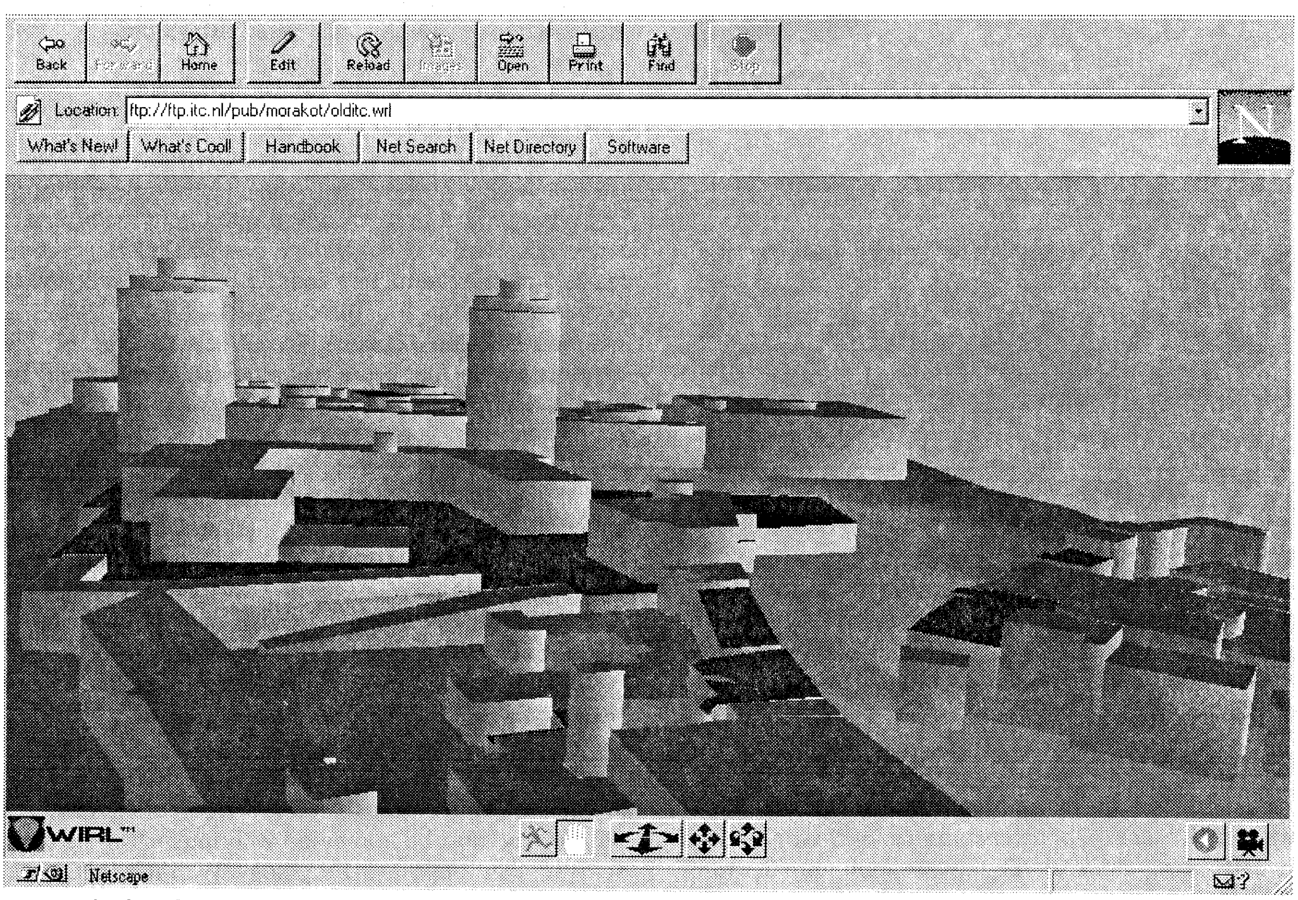


Figure 5 b The old ITC in its virtual environment.

The case studies have shown that the 3D-FDS offers good possibilities of spatial analysis for applications where the real world can be described by solid objects, surface, line, and point features. The data model supports a wide range of queries, from simple class retrieval to metric queries and complex topologic ones.

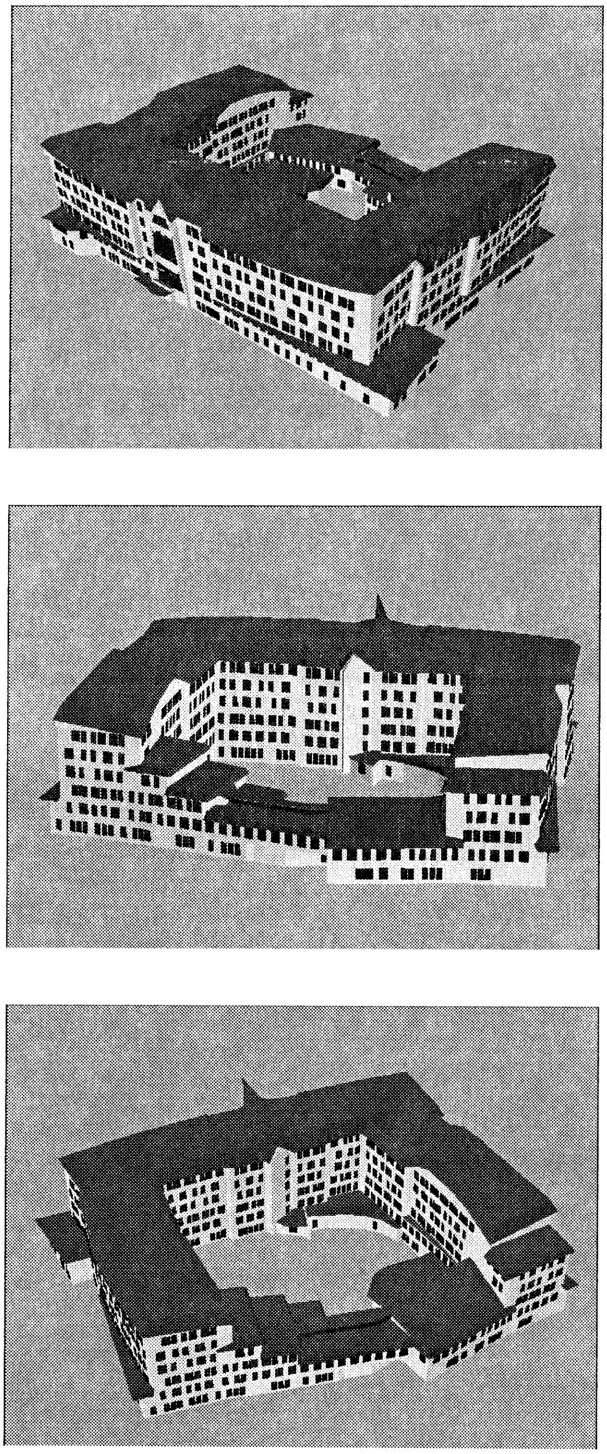


Figure 6 The new ITC.

Analytical and digital photogrammetry can deliver 3D topographic data. Although measuring by photogrammetry is traditionally done in 3D, the transition from 2D to 3D models considerably increases the effort needed for data collection and data structuring. It also drastically expands data volumes. Manual extraction of houses does not pose fundamental problems, only practical ones. Until further progress is made in semi-automatic extraction, strict digitizing rules should be followed to minimize measuring time and facilitate automatic 3D model construction, especially in cases of complex buildings and when a high level of detail is required. We have not yet accomplished fully automatic model construction, since building of topology is significantly more demanding in 3D than it is in 2D. Stereosuperimposition of 3D wireframes is useless if there is no hidden line removal, since it becomes indecipherable. It is also useless for interactive correction if the digitizing software does not support 3D topology. Conventional stereoplotting software can only keep the roof polygon 'alive' when we move a corner point, but cannot modify the walls accordingly. Attempting to change a corner point of a footprint would be an even more insane undertaking since the coding system only recognizes roofs, thus even off-line rebuilding of topology is not possible.

Current DPs offer a higher level of computer support than APs, but this does not concern feature extraction for topographic mapping. Our comparative tests using the C120 and the T10 showed no significant differences in time efficiency, which conforms with the results reported by (Colomer et Colomina, 1994). This implies that the additional costs of working all-digitally cannot be recovered yet, unless a hybrid analytical-digital production line is set up for 3D data collection or a significant productivity boost is attained through automating feature extraction.

5. FURTHER DEVELOPMENT

Digital photogrammetry offers the prospect of automated information and texture extraction from photographs; in both it is distinct from analytical photogrammetry. Semi-automatic, local image matching on digital plotters seems feasible on short term, thus speeding up reconstruction of certain objects such as roads and buildings. Once the geometry of the topographic objects is known, the candidate areas for texture mapping can automatically be extracted form the digital images.

Apart from (semi-)automating object recognition and feature extraction, system enhancements are also needed, especially for efficient quality control and updating operations. Such desires require very powerful graphic subsystems with large image memory for effective viewing of object reconstructions. Because of the possibility of occlusions in built up areas and the countless number of possible object shapes and compositions, only a direct visual comparison of object reconstruction with the original images can give a final validation. Efficient verification would be possible if an object could be viewed--almost instantaneously--in more than one stereomodel. Adequate 3D viewing must be combined with interactive digitizing software that supports 3D topology. With fully automatic extraction of topographic information from aerial photographs still miles away, extended image access and computer graphics ('integrating digital photogrammetry and CAD') will increase productivity of 3D vector data acquisition and thus make a broad introduction of 3D-GIS more feasible.

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DTMs can be produced by automatic image matching--for medium and small scale images--and subsequent manual verification and editing. To meet the increasing demand for higher resolution DTMs, further research and development work is needed to be able to efficiently deal with multi-valued surfaces and occlusions. Verification of a DTM and interactive correction would benefit from a superimposition on the stereomodel in terms of faces (semi-transparent or on-off toggling), and not only points and lines as offered by present DPs.

Reverse photogrammetric engineering, *ie,* producing synthetic stereoscopic images for realistic viewing of virtual urban scenes from a digital 3D model, is yet another challenge to software and graphic workstation development.

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KURZFASSUNG

Ermutigungen um dreidimensionale Geoinformationssysteme zu behandeln, kommmen aus zwei Richtungen, dem technologischen Fortschritt und den höher gespannten Erwartungen der Gebraucher, die zunehmend komplexere Aufgaben zu lösen haben. Die Anforderungen an räumliche Information sind besonders hoch in Stadtgebieten. Der Aufsatz behandelt wie derzeit verfügbare photogrammetrische Mittel für 3D-Stadtkartierungen eingesetzt werden können. Ausgehend von der Zielsetzung ein umfassendes räumliches Informationssystem zu schaffen, stützen wir uns auf ein Datenmodell, das auf der *3D formalen Datenstruktur* (3D-FDS) basiert. Neben der grundsätzlichen Frage nach dem geeigneten Datenmodell und der Entwicklung der notwendigen Hilfsmittel für die räumliche Analyse und Darstellung, ist die effiziente Datenerfassung ein Hauptproblem wenn man den Kostenaspekt eines 3D-GIS betrachtet. Selbst ohne automatischer Bildauswertung bieten dazu Luft- und terrestrische Photogrammetrie Lösungen an, sowohl zur Rekonstruktion der abgebildeten Objekte, als auch zur Texturerfassung. Um die Anwendbarkeit entwickelter Konzepte und bestehender Mittel zu prüfen, haben wir ein experimentelles 3D-GIS gebaut. Wir berichten darüber und die damit gesammelten Erfahrungen und bieten Vorschläge für Weiterentwicklungen von photogrammetrischen Systemen.