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Managing Large 3D Urban Databases

MICHAEL GRUBER, Graz

ABSTRACT

The three dimensional digital data of objects of a city has shown to be a powerful tool for many applications. Namely the planning of wireless networks in cities, the support of decision making processes for urban development projects, the simulation of pollution distribution or the support of civil and military security operations. Today the initial commercial driver for the creation of such data for entire cities is the telecom industry, optimizing their communication networks depending on line-of-sight analysis. In addition to the presentation of the shape of urban objects we have observed the need for an enhanced realism of these data by exploiting the radiometric information of images. Creating such fully three dimensional city scapes has turned to be the key technology for a various number of novel applications, even if the acquisition of missing source data and the maintenance and administration of these huge amount of data needs to be better organized.

Remote and local access to the data, fast interaction and electronic links to other urban information systems turns this into a concept of a hypermedia data base system, which is the unavoidable next step in improving the data for the management of our growing cities.

The basic instrument of this technology is the digital graphics workstation, which is able to handle and visualize large sets of vector and raster data. In line with this development of graphic computers, we observe a strong development in the domain of computer graphics applications, namely methods and algorithms to organize, handle and visualize digital graphics data. Methods for the documentation of existing objects exploit these skills in addition with the well-known techniques of image data acquisition, photogrammetric processing, surveying and GIS technologies. In this contribution we discuss several aspects of the digital documentation of large objects like an entire city and focus on interactive data visualization.

1. INTRODUCTION

The transition from the two dimensional geographical information system to the completely three dimensional description of a city´s environment (3D GIS) is the modern issue of urban data management. Strong research and development activities take place in order to support this important step in the evolution of a city´s data management system. And we recognize, that not only the reconstruction and representation of the 3D shape of buildings and other objects of the city are the issue, but also the description of surface properties and material parameters have become part of the data base. This novel extension of the data set is currently managed by the extraction of photo texture from images and causes a new dimension of hardware and software capabilities. Vector data and storage space intensive raster data have to be processed, maintained and rendered at one time. The entire process consists of several steps (e.g. source data creation, database content creation, rendering and visualization, up-date and maintenance etc.) wherein we have identified two bottlenecks, which currently avoid the breakthrough of this data base concept:

- the quality-cost ratio is to low because of the labor-intensive creation of a full fledged photo-textured data base;
- the accessibility of the data base is limited to the end-users, essentially due to a lack of structure capable of organizing the data and capable of providing network access to remote users.

If these problems are solved, we argue that there exist such important needs that the commercial interest on such data will evolve and that the concept of the geographic information system will be subsumed into a hyper media information system. In this article we present a concept, how large urban data base contents are organized by a special data structure, which supports levels of detail (LoD) and spatial data retrieval to allow fast access and real time visualization for fly-over and

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walk-trough applications with unaided computers devoid of special hardware. The structure of the data base content has to be tuned with respect to the application and their need for quality of the representation and their need for spatial pre-selection of the data. Differentiating the data base content, allowing local and remote access to the data base and connecting the data base to other information systems are the key steps from pure CAD models towards urban information systems of the future (cf. Tab.1).

Information Level	System
Geometric description and surface properties of objects Geometric description of the terrain	CAD Model DTM, CAD-Model
Information System and Data Base Management System	2D-GIS, 3D-GIS
Local and remote access to the data base	GEO Server
Links to other information systems	CyberCity

Table1: Levels of the Urban Information system.

2. TOWARDS A 3D DATA BASE

Virtual Reality vs. 3D-Geographic Information Systems

Since the last decades computers have been used to generate images and image sequences of virtual scenes. We have seen the presentation of fantastic worlds created purely from imagination. Designed without any relationship to the real world these data do not represent existing objects. Mostly supported by developments from the computer graphics domain these VR-applications have produced important results, which are highly appreciated. The quality of rendering and visualization in this field is the milestone for digital modeling of existing objects.
Today we observe that virtual presentations of existing objects are finding increasing use in applications which have to be realistic and faithful. Training and simulation systems, e.g. in the medical, military and industrial fields, exploit the latest outcomes of computer graphics research. Photorealistic renderings are needed in many other applications [Leymarie, 97]. One of them is the digital presentation of cities where the user can visit places, streets and finally the interior of buildings as a virtual tourist (cf. Fig. 1). The quality of such photo-realistic presentations has to be high and may require expensive visualization equipment but finally it depends on the quality and the faithfulness of the CAD database, i.e. the geometric shape description and surface representation of the urban objects. Both, the vector data representing the geometry of objects, and the raster data containing information of surface properties have to be treated as documents. Source data acquisition for the initial data base content creation and update of these data is the issue to separate the three-dimensional information system from virtual reality applications. Nevertheless these data have to be completely three-dimensional. Existing two-dimensional GIS database contents cannot fulfill the requirements of such virtual presentations of urban areas. The 2D map has to be replaced by a 3D photorealistic data base. This process is expensive and labor intensive. Till now, there exist no automated procedures to create geometric descriptions of objects from images, range sensors and/or existing map data.

Figure 1: Visualization of three dimensional and photorealistic data of buildings. Left: A place in a City (Eisernes Tor, Graz, Austria) and the interior of a building (National Library, Vienna, Austria). Both data sets consist of vector and raster data (shape and surface properties).

Data Base Content Creation

Data base content creation for three-dimensional geographic information systems suffers from missing source data. Currently we have access to aerial photographs and data from terrestrial surveying. Novel range sensors are currently on the way towards operational use and high-resolution satellite images promise to be an inexpensive data source of the near future. Additional data contain collateral information or semantic information These data are sufficient to establish or up date a conventional 2D geographical information system or to reconstruct a course three dimensional geometry of buildings (shape of roofs, building boxes).

To refine the geometry of the cityscape and to document surface properties of vertical faces (like the facades of buildings) we need source image data from these surface elements. These terrestrial images are currently taken from the street level using conventional photo-cameras, video or still video equipment. A novel method of recording a cities facades is shown by Maresch [Maresch, Scheiblhofer, 1996]. Line CCD technology has been exploited to equip a mobile imaging system, which is designed to create source data for geometric reconstruction and extracting phototexture.

A major task within the procedure of data base content creation is the reconstruction of objects exploiting the existing source data. Automation of this important step is an issue (we have identified the modeling procedure as a labor intensive and therefore expensive bottleneck). Since the beginning of this decade we observe intensive activities concerning this field of science. Experts in image analysis and pattern recognition are investigating the potential of feature extraction from aerial images of large scale and show promising results. Though the most important source images are overlapping aerial images taken by large format cameras the highest effort was made in reconstructing from vertical aerial images ([Shufelt,McKeown, 1993], [Lang, Schickler 1993], [Pasko, Gruber 1996], [Henriccson, 1996]). Semi-automatic methods are currently investigated by e.g. [Grün, 1996] and have shown pretty good results.

Since laser based range images are available, the fusion of range images and intensity images have been investigated [Haala, 1994] and seem to evolve to a unbeatable tool for further automation. In addition to airborne sensor data we have identified the need for terrestrial data to record facades of buildings and other vertical faces of the city's objects [Gruber et al, 1995].

The procedure of data base content creation is many folded. If buildings are the most important class of three dimensional features of urban areas, we have to accept traffic areas and constructions

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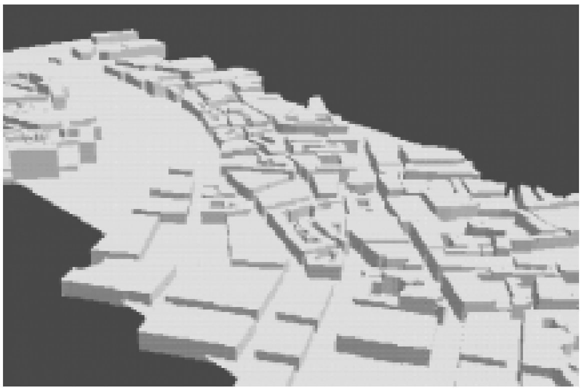
related to urban traffic systems as the second important group. Automation for street detection and street reconstruction is investigated by e.g. H. Maitre [Maitre 1996].

The Impact of Photorealistic Texture

Pure geometric data visualized through a graphic system needs a high effort during the interpretation by the user. If these data are three dimensional, it may cause severe difficulties or may be even impossible. Comparing the technical drawing with the visible image of the real word turns to be a task only for skilled experts. If the information system is able to present the digital data in a more natural way, we will understand quicker and better what the data are about.
One convenient method, which is widely used is the presentation and description of surface properties of the cities objects by photo texture (cf. Fig. 2). Aerial images are exploited for roofs, terrain and other horizontal faces. Facades and vertical faces have to be recorded by additional photographs taken from the street level. Photo texture is -compared with the geometry data-very storage space intensive (cf. Tab. 2).

Face Class	**Size (m^2)**	**Pixel Size (cm^2)** high/med/low resolution			**Texture Size(kByte)** high/med/low resolution		
Roof	280	10	10	25	84	84	13
Facade (low)	400	16	16	25	47	47	19
Facade (high)	500	2	8	16	3750	234	59
Detail	10	1	-	-	300	-	-
Terrain (low)	1750	50	50	50	21	21	21
Terrain (high)	250	10	25	50	75	12	3
Total amount of texture data for the entire city (GByte)					**855**	**80**	**23**
Total amount of geometry data for the entire city (MByte)					**250**	**80**	**50**

Table 2: The multiple resolution concept of texture and geometry data and quantities of digital data for one building and an entire city of 200 000 buildings at three different levels of resolution.



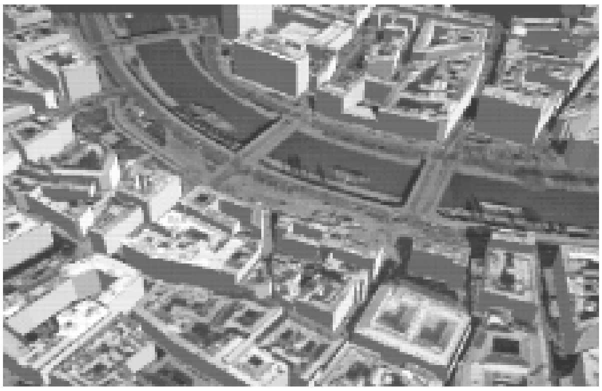


Figure 2: Three dimensional data of a city. Left: Pure geometry data at a course level of detail (building blocks and terrain data); Right: Phototexture from aerial images mapped onto the horizontal surfaces of the model.

3. ORGANIZING LARGE QUANTITIES OF DATA

If a system is designed to handle the fully fledged 3D data base of an entire city, including geometry, photo texture and additional information we have to be aware of an amount of some hundred GigaBytes of data. And we know, that visualization must handle perspective projection and oblique viewing points. One concept of handling these data is was investigated by [Kofler et al. 1996]. Based on an object oriented data base management system (OODBMS) a segmentation of the data is done following the concept of r-trees. Not only the structure of the tree is presented by the objects of the DBMS, but also data in different resolution and by different level of detail (LoD) are stored in the hierarchy of the r-tree. The viewing frustum of the virtual visitor cuts these parts which have to be visualized apart from the entire data set.
The access to the data of the three dimensional photo textured digital model of the city is made possible by the rising network infrastructure. Access to other information systems will be available and managed by the 3D City Model and its Hypermedia functionality. The traditional use of the geographical information system is expanded and opened for applications like virtual tourism, navigation, entertainment, education, legal, historical and commercial information visualization and many more.

Relations vs. Objects

Large data bases need to be organized using special data structures [Samet, 90]. The design of these data structures has to be tailored to meet the requirements of the user. The traditional two-dimensional geographical information system (2D GIS) has exploited the characteristics of relational database management systems (RDBMS). This was good enough for most of the GIS tasks like maintenance, update, spatial analysis and fast data retrieval. Visualization and rendering of 2D GIS data was strictly organized using rectangular viewports. The content of the visualization was defined by the scale of the presentation and selected by layers or similar mechanisms. However, modern urban data management has to deal with more complex requirements and maintain more complex data. It is obvious, that a novel data management approach has to replace the relational concept. This is currently in progress and we observe object oriented database management systems (OODBMS) or at least object relational data base management systems (ORDBMS) replacing the old ones. For visualization purposes of large 3D GIS data sets a data structure was designed and implemented by [Kofler, 1998]. The idea was to combine the R-tree concept and the level of detail (LoD) concept and organize the data using an OODBMS.

R-trees and Levels of Detail

The R-tree data structure has proved to be a useful concept for storing and organizing spatial data. Compared with other spatial data structures like Quad-trees or Oct-trees, it is obvious that R-trees are better suited for the organization of overlapping objects, i.e. the rectangular bounding boxes of the 2D or 3D CAD models of buildings, building blocks and larger urban units. The crucial idea is to combine levels of detail and the R-tree concept in order to store CAD data of a particular level of detail at a specivic level of the R-tree, i.e. each level of the R-tree contains not only pointers to other levels but also data [Kofler, 1998] (cf. Fig. 3). The retrieval of these data can be performed as soon as the level of detail and the required area of interest has been chosen.
The definition of the rectangular bounding boxes (the R-tree elements) can be done based on any meaningful concept e.g. choosing the entire city, the administrative districts, city blocks and single buildings as the contents of the different levels of the R-tree. In keeping with this subdivision of the city it is necessary to define the levels of detail of the CAD representation, which can be related to a particular level of the R-tree, i.e. a distinct set of bounding boxes. A possible result of these

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considerations is shown in Fig. 4. The data base content of the entire town is broken down into four levels of the R-tree structure and three levels of detail.

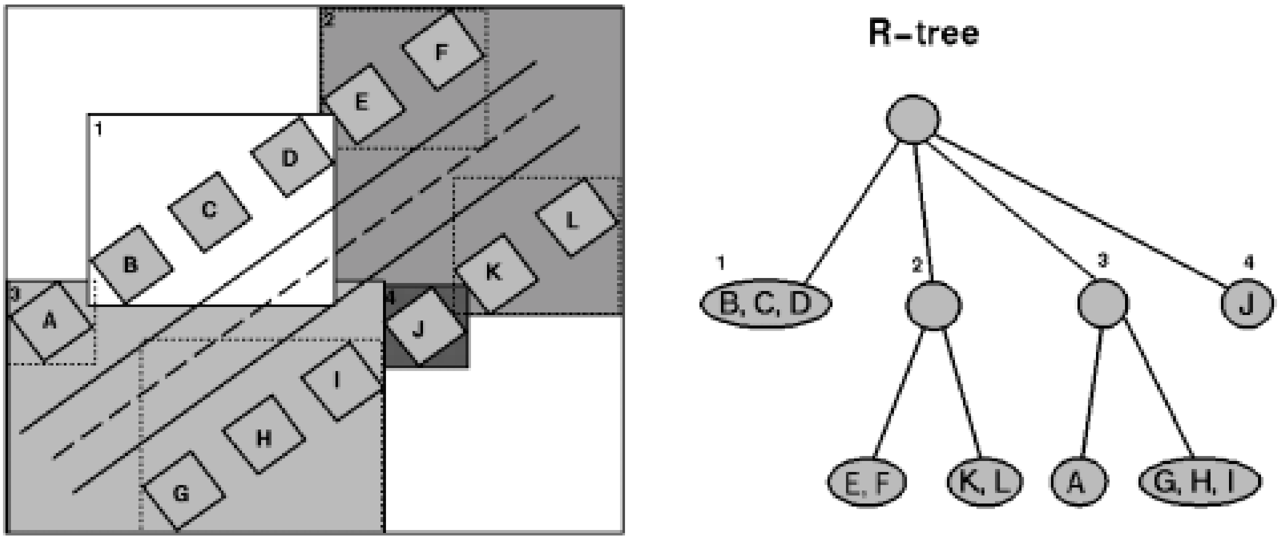

Figure 3: Principal concept of the R-tree data structure. Buildings on both sides of a street are organized by rectangular bounding boxes (left) and the related R-tree (right).

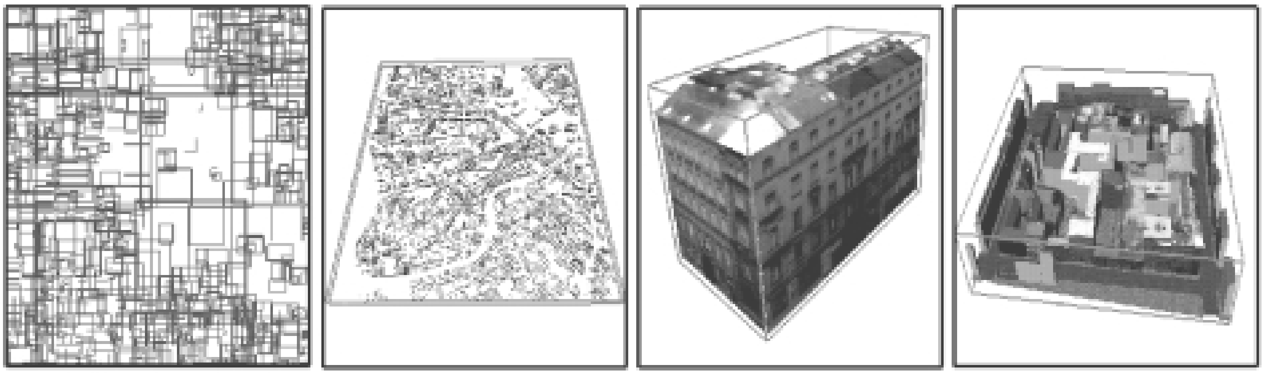

Figure 4: R-tree structure of an entire city and related levels of detail. From left to right: Level 0: Entire city, links to the lower R-tree level, links to the 2D GIS (optional), no CAD data. Level 1: One district, links, low resolution CAD data. Level 2: One city block, links, medium resolution CAD data. Level 3: One Building, links, high resolution CAD data.

4. VISUALIZATION OF LARGE 3D-GIS DATA SETS

The interactive and perspective visualization of large three-dimensional GIS data sets needs a special hardware and software environment, if a reasonable frame rate is required. For this purpose advanced graphics boards have been developed and are available on the market (cf. [Akeley, 93]). Necessary software components and graphic libraries (e.g. OpenGL) are also available thus the creation of 3D visualization software to run on low or mid level desktop workstations is no longer an impossible task. In order to achieve a convincing performance for real time interaction, one has to organize and retrieve the data base content using methods which are optimized to support the rendering process of the graphics system. The following techniques have proven to be the most useful techniques for perspective rendering of large scenes:

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Culling is used to pre-select the data base content based on visibility conditions. In the case of perspective visualization it is the intersection of the data domain with the view frustum. It may also be used to distinguish between different levels of detail, i.e. the subdivision of the visible space into foreground, middleground and background. Less complex culling conditions may be defined by a simple distance measure or a background plane.

Levels of detail have already been mentioned and are used intensively. A sequence of CAD models (vector data) of various resolutions and quality (different levels of detail) for each object is prepared and stored in the data base. The payload for visualization can now be scaled by choosing a specific level of detail for an object, e.g. in combination with the culling mechanism. A multi resolution concept for images (e.g. an image pyramid) is the equivalent method for raster data.

Progressive rendering controls the update of the scene rendering by optimizing the refresh rate to match the quality of the rendering. The mechanisms are e.g. a reduction of the area of visibility (exploiting the culling procedure) or a reduction of the quality (based on the level of detail structure).

Dynamic loading has to be applied, if the entire data base of a large city is to be made available. Here it is no longer possible to keep all data in the memory of the workstation. The dynamic loading procedure needs a well organized data base and a fast data retrieval mechanism to provide the user with the necessary subset of data just in time.

The results of a careful application of these methods are presented by two different implementations, both handling large sets of geographical data.

The Vienna Walkthrough System

On application of managing the geometry data of an entire city was designed and implemented by [Kofler, 98] at the Institute for Computer Graphics and Vision. The purpose of this system was to make the entire geometry of the city of Vienna available for interactive visualization. The data set contains 20 000 building blocks acquired by traditional photogrammetric methods. These data have been transferred into a completely three dimensional data structure; different levels of detail have been created and organized using the LoD-R-tree data structure. The implementation was done on Silicon Graphics Indigo2 and Silicon Graphics O2 workstations.

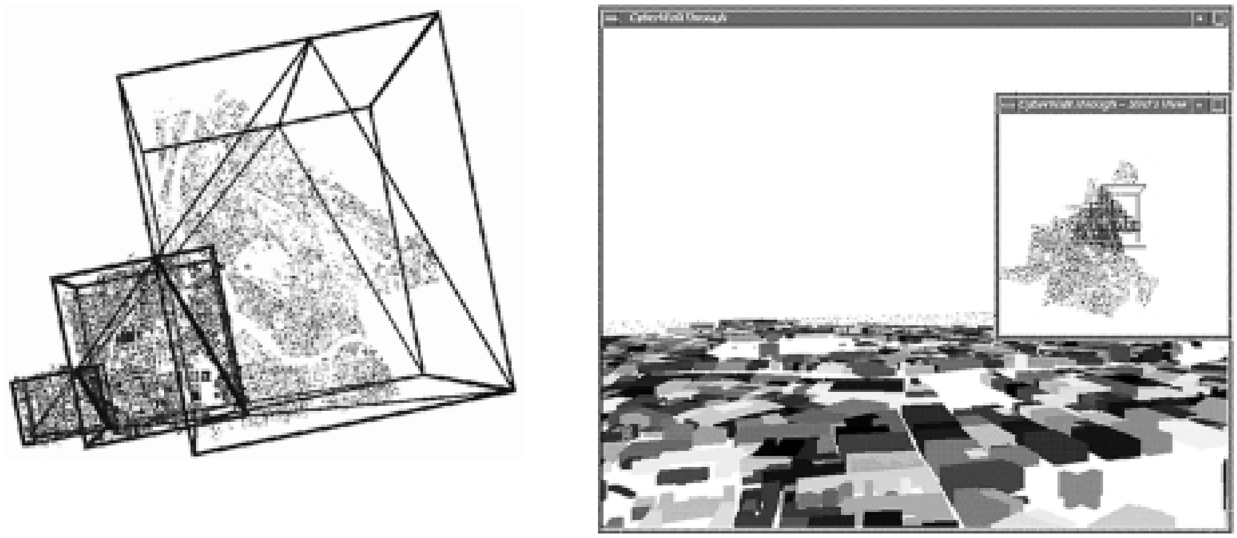

Figure 5: The Vienna walk trough System, as implemented on a Silicon Graphics desktop Workstation. The navigation during interactive visualization (large viewport, right) is supported by a vertical view (small viewport, right). The data loading is organized through a 3D view frustum (left).

The Styria Flyover System

The Styria Flyover System [Kofler et al., 98] handles terrain data and texture data for the entire province of Styria, Austria. The entire scene covers about 17 000 km^2 and shows a mixture of flat land and mountainous regions. Texture data have been derived from the Landsat TM remote sensing system with a ground resolution of 25 m. The mesh width of the digital raster terrain model (RDTM), which is maintained by the GIS/LIS department of the local authority, is 50 m. The entire data set contains more than 6 million height values.

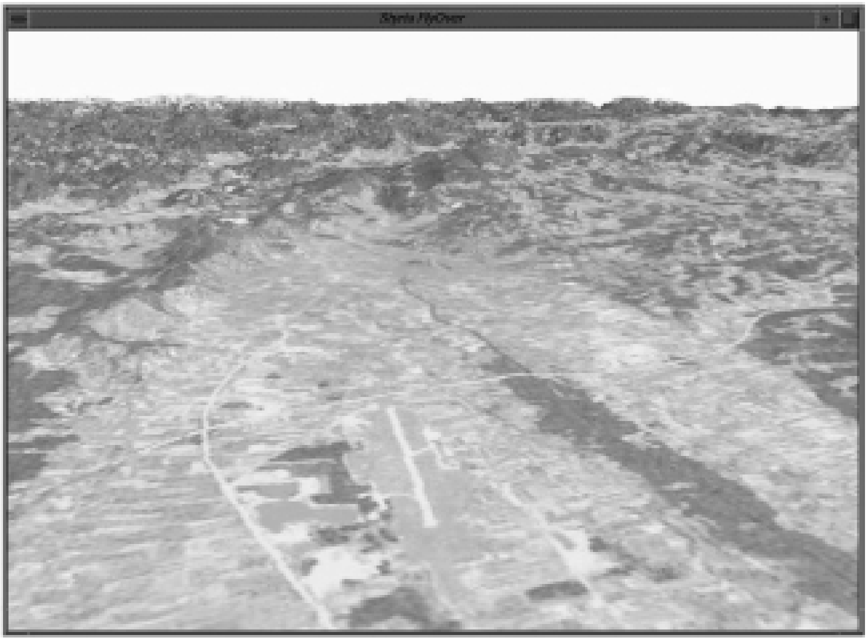

Figure 6: The Styria Flyover System has been developed by [Kofler, 98] and illustrates how geometry and texture data have been structured for visualization on a desktop workstation. The entire area of the province of Styria, Austria, (approx. 17 000 sqkm.) is available for interactive visualization.

5. CONCLUSIONS

The development of computer graphics systems has prepared the way towards the fully visual presentation of data. We know, that this development is necessary, if information of complex object has to be presented and visualized for fast interpretation. A growing city is such a complex topic. The relationship of the cities objects - buildings, traffic constructions and many other installations - is manifold. Data retrieval and data access of information systems of cities need to handle with this complexity. There is no doubt, that urban data management of the next century needs excellent tools and a powerful man machine interface to meet the requirements of future applications if the 2D geographic information systems shall be overtaken by fully three dimensional information systems. This development will bring new and large amounts of data, which need to be acquired, updated, maintained and retrieved. Only if those data have sufficient quality, if the visualization of the data makes interpretation easy and if data base management systems are able to allow interaction with those data from local and remote users site the effort of creation and maintenance will be justified.

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