URBAN DATA ACQUISITION FOR TELECOMMUNICATION PURPOSES IN EUROPE

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ABSTRACT

Three dimensional digital data of cities are of growing importance for various applications. One is the planning of cellular radio networks for mobile communication purposes. This special application has distinct requirements to be met. Most important is the propagation of field-strength in urban areas, which has been developed into a sophisticated method. The loss of the electromagnetic energy is propagated along different tracks over the roofs, through street canyons and even via reflecting walls of buildings. The basic data set for this simulation and propagation process is a precise three dimensional description of the surface of the terrain and the shape of buildings and other objects. The acquisition of these data combines methods which are already established such as traditional aerial photogrammetry with new methods such as digital image analysis, which is used to automate the photogrammetric procedure, as well as laser scanning methods, which have been developed during the last five years and promise to be a powerful and highly automated tool for urban data acquisition.

In this contribution we report on European activities in urban data acquisition, especially for telecommunication purposes. The needs for quality, geometric resolution and actuality are discussed. Finally we present projects from Austria which have been carried out in cooperation with the first author's firm.

1. INTRODUCTION

The transition of two dimensional geographical information systems to a fully three dimensional presentation of urban environments has shown to be an important current issue. Not only the acquisition of the three dimensional shape of the objects in the data base but also data structuring and data retrieval as well as visualization and rendering have to be developed to meet the requirements of a 3D GIS. One special application derives from the needs of planning telecommunications networks, especially for built up areas. In this application, the elevation data of the terrain are not sufficient but also the three dimensional shapes of buildings are needed. Based on these data, field-strength propagation models are exploited in order to simulate the wave distribution and to plan additional antenna positions. Due to the emerging use of mobile telecommunication facilities the network of base stations is enhanced continuously and a dense grid of so-called micro-cells at a size of less than 1 square-kilometer is used to meet the requirements of the system.

This application scenario calls for consideration of the quality of the three dimensional data, of the method of data acquisition, of the organization of the data, their storage and retrieval and, if possible, of the method of exploitation within other applications.

2. URBAN STRUCTURES FOR CELLULAR NETWORK PLANNING

The planning of cellular networks for mobile telecom applications requires data of specific quality and actuality. This exceeds the mere terrain elevations to include the shape of buildingsfor signal propagation modeling. The so-called 3D Urban Micro-Cell Model (Cichon et al., 1993) employs vertical plane, horizontal plane and multi-path scattering and needs 3-dimensional object data. An accuracy of better than ± 2 m is needed (Siebe, 1996; Table 1).

Combined data set of terrain and buildings
Grid size 5 * 5 meters
Accuracy of ±2 meters
All buildings larger than 50 sqm and height of more than 3 m
Representation of buildings as coarse building boxes (flat roof)
Height difference between terrain and roof
Decomposition of building blocks if heights differ by more than 3 m

Table 1: Requirements to data base content of city structures according to Siebe (1996).

These requirements will be enhanced in line with the development of more sophisticated propagation models. In addition to the enhancement of the geometric accuracy, it will be necessary to incorporate reflectance parameters, vegetation and geometric details. The enhancement of geometric resolution and accuracy will also cause raster models to need significant computing time as well as storage space. This disadvantage will be overcome by using vector data. We propose this and show in an experiment how vector data can be managed, retrieved and visualized by exploiting existing computer graphics technology.

3. URBAN DATA ACQUISITION IN EUROPE

Data acquisition of urban areas is of high interest to researchers as well as to data base content creators and users. In terms of productivity, photogrammetry has been the most efficient method for many applications, definitely if the shape of roofs and the height of buildings need to be considered. One pioneering project initiative dedicated to the acquisition and application of 3D urban data was carried out by the Institute for Photogrammetry, University Bonn, Germany, under the leadership of Prof. W. Förstner on behalf of the OEEPE (Organization d'Etudes Photogrammétriques Expérimentales). The goal of this project was to relate data produced at various levels of detail and accuracy to some applications. The project's result (cf. Fuchs, 1997) has shown that 3D data of buildings at an accuracy between ±0.5 meters and ±1.0 meters are of high interest to a large community of users, among them the telecommunications industry. The most relevant sources of data are aerial images, followed by existing maps and terrestrial surveying, where true 3D data are only available by exploiting aerial images. Even though one may be concerned about the fact that the data produced for simulation purposes in telecommunications projects are currently acquired at a slightly lower level of accuracy and detail than what traditional urban mapping would produce, there is the mitigating consideration that these data cover entire cities and not only specific project areas.

Currently such 3D data of cities include terrain elevation data and the shapes of buildings and are available for most of the larger cities with more than 150 000 inhabitants in many European countries (e.g. Germany, Belgium, Austria, Netherlands); for most of the other European countries at least one or two major cities are covered.

4. TELECOM PROJECTS IN AUSTRIA

During the last five years the larger cities of Austria have been equipped with cellular network facilities for three competing national mobile telecommunication vendors. Since data for planning and modeling were previously not available in the market it became necessary to acquire the geometric urban data. Since automated methods initially appeared to not yet be sufficiently developed at an operational level, the database contents were created manually. In each case a photogrammetric measurement procedure based on aerial images was chosen to meet the given requirements (cf. Tab. 2).

City	Size (incl. Suburbs)	Buildings or Building	Inhabitants

		blocks	
Vienna	400 sq-km	34 000	1,600.000
Graz	128 sq-km	17 000	240.000
Salzburg	65 sq-km	5 600	140.000
Linz	96 sq-km	3 000	200.000
St. Pölten	118 sq-km	2 300	52.000
Bregenz	30 sq-km	1 500	25.000

Table 2: City structures acquired for cellular network planning in Austria.

The largest project was performed in the city of Vienna, capital of Austria. The project covers an area of more than 400 sqkms and contains about 200,000 individual buildings. Aerial images at a scale of 1:30,000 were used in an analytical photogrammetric workstation, where measurements could be performed at an accuracy of ±1m. The level of detail of these data was chosen to be low. Buildings of similar height were merged and mapped as single objects (e.g. building blocks) and roof shapes were ignored. A building or building block was described by 4 to 10 single point measurements for the roof outlines, one additional point for the average elevation of the roofs above the terrain, and a final point to define the elevation of the surrounding terrain The throughput of this manual acquisition task was rather high. About 60 to 80 three dimensional objects were measured within one hour. The effort for the entire project was about 500 labor hours excluding project preparation, image set-up, aerial triangulation and data processing.

The raw data acquired by photogrammetric measurements were postprocessed in a semiautomatic manner to verify the topology of the 2D polygons and, if necessary, to corrected them. The roof and terrain height information was added to the polygons and used to calculate the height of each building. Finally the data were transformed into the given UTM coordinate system (cf. Tab.3 and Fig. 1).

Project	**Aerial Image Data**	**No. of Stereo Models**	**No. of 3D Objects**	**Size of Data Set (3D)**
Vienna I	B/W, Scale 1:30 000	9	20 594	50 Mbytes
Vienna II	B/W, Scale 1:30 000	10	12 935	28 Mbytes
Total		19	33 529	78 Mbytes

Table 3: Data sets of Vienna: Vienna I contains the data from the central part of the city
Vienna II consists of data from the suburbs.

5. DATA STRUCTURES AND REPRESENTATION

Urban data structures as derived for telecommunication purposes differ from existing traditional 2.5 D GIS data. They show a specific structure which supports the simulation of signal strength, but they do not conform to the topological requirements of GIS data. Such urban structures typically show the following sequence of data:

- Number of polygons
  - Name of polygon (roof outline)
    - Number of points per polygon
    - Measured building height
    - Sequence of 2D vertices
  - Name of polygon (roof outline)

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These data are projected onto the DTM (height of the bald Earth) and are transformed jointly into a unique coordinate system like UTM. The roof outlines are closed polygons, which do not contain insular polygons and must not intersect with neighboring polygons. Common vertices of two adjacent polygons are registered once for each polygon, a fact which violates common rules of GIS data base contents.

6. FURTHER DEVELOPMENTS

Besides the pure simulation and network planning task for mobile telecommunication applications, we have investigated generic methods to support three dimensional simulation, visualization and interaction with the data. Three dimensional data structures and culling methods have been implemented for this purpose. We argue that such methods, used in the computer graphics domain for real time rendering tasks, fit perfectly well to the simulation task of signal strength modeling.

Figure 1: Planimetric view of the Vienna data set (Vienna I)

6.1 From 2.5 D to 3 D

Polygon descriptions as discussed above do not represent a fully three dimensional data base. The data structure consisting of 2D polygons and height information represent the so-called 2.5-dimensional system. It is necessary to invoke additional procedures to produce 3D objects from of the 2.5 D data. In our approach the new data format is based on the OpenInventor file format and contains a point and face list for each object, including normal vectors and material properties such as color and reflectance parameters. In a case study the entire data set of the City of Vienna was stored into a 50 Mbytes file, which was too large to be visualized at a medium range graphics computer in a real time manner, which would typically have to create an image in 1/20 of a second. A special data structure, which allows culling and level of detail management was developed to support real-time visualization, interaction and fast data retrieval at a rate of at least 1/10 second per image to still qualify as “near real time”.

6.2 Real Time Simulation and Visualization

Fast simulation and visualization of large 3D data sets needs special data structures for access and data retrieval. The issue was to design a sufficient data base management concept and a sufficiently powerful tool for real time manipulation of the data.

6.3 Data base design: Relations versus Objects

Large data bases need to be organized through a special data structure. The design of this data structure has to be tailored to meet the requirements of the application. The traditional two-dimensional geographical information system (2D GIS) is based on relational database management systems (RDBMS). This was satisfactory for most GIS tasks like maintenance, update, spatial analysis and fast 2D data retrieval. It is obvious that a novel data management approach has to assume 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). In our approach we combine the R-tree concept and the level of detail (LoD) concept and organize the data by an OODBMS. We propose to use this data structure for real time visualization as well as for simulation like antenna signal strength modeling.

6.4 Data Base Design: R-trees and Levels of Detail

The R-tree data structure has shown to be a useful concept to store and organize spatial data. Compared with other spatial data structures like Quad-trees or Oct-trees it is obvious that R-trees better support 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 and to store CAD data of a distinct level of detail at a certain 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, and Fig. 2). The retrieval of these data can be performed as soon as the level of detail and the required area of interest have been chosen.

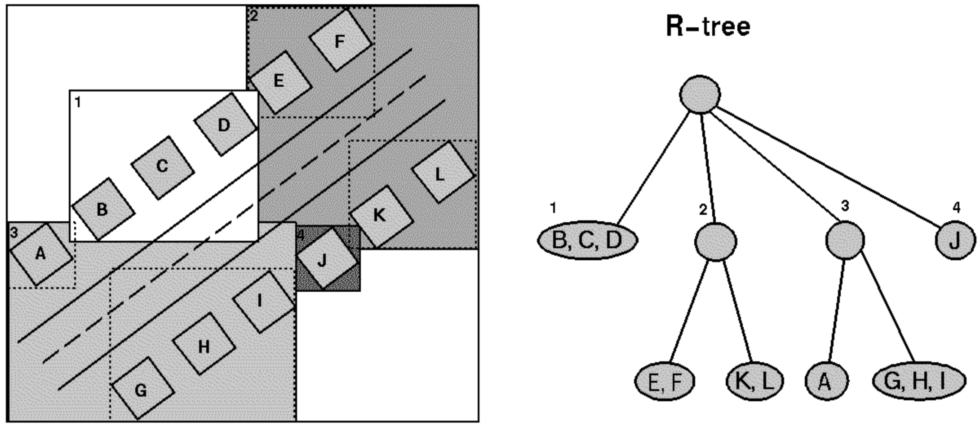

Figure 2: Principal concept of the R-tree data structure. Buildings on both sides of a street are organized by rectangular bounding boxes (left) and the related R-tree (right), from Kofler (1998).

The rectangular bounding boxes (the R-tree elements) have to be defined by one of several meaningful concepts, e.g. choosing the entire city, the administrative districts, the area of micro cells, city blocks and single buildings. In line with this subdivision of the city it is necessary to define levels of detail of the CAD representation, which can be related to a distinct level of the R-tree, i.e. a distinct set of bounding boxes. A possible result of these considerations is shown in Fig. 3. The data base content of the entire town is organized and segmented into four levels of the R-tree structure and three levels of detail.

6.5 Managing Large 3D-GIS Data Sets

The management of large three-dimensional GIS data sets needs tools to support fast access to the data. In order to achieve a convincing performance for real time interaction we have organized the data base content by methods which are optimized to support fast data retrieval. The following techniques have proven to be the set of most useful techniques for this purpose.

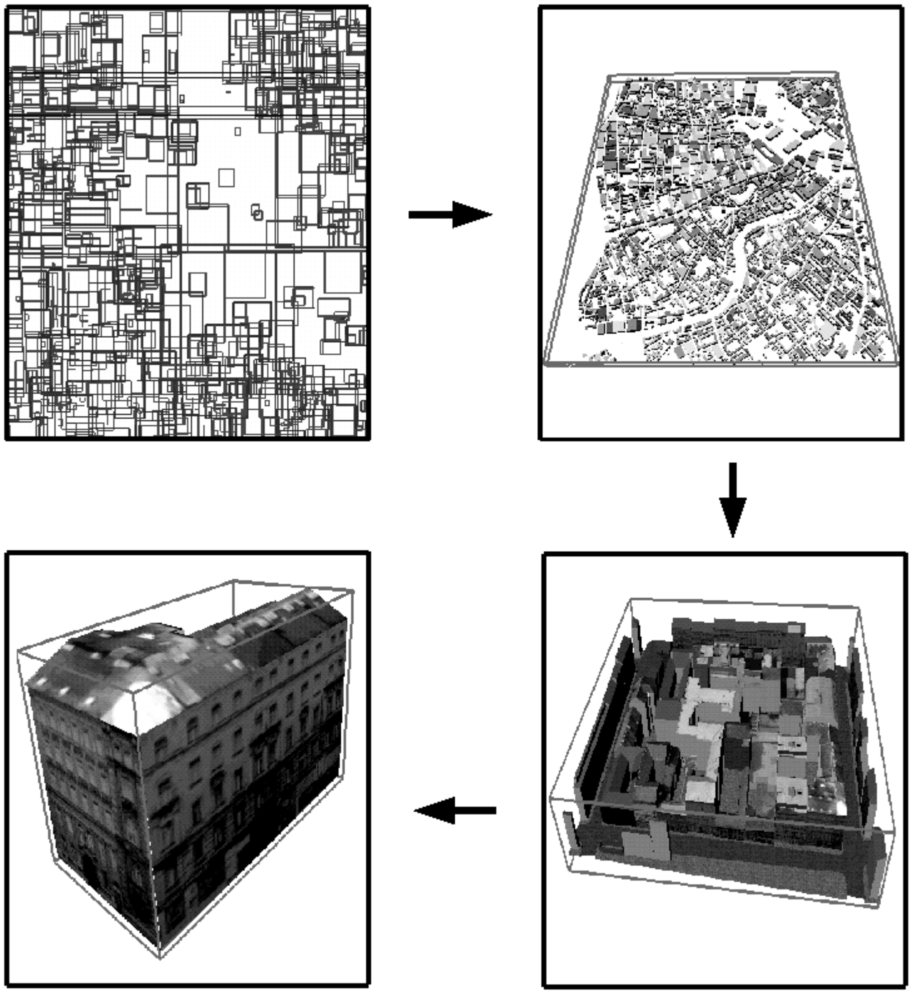

Figure 3: R-tree structure of an entire city and related levels of detail. From upper left clockwise:
Level 0: Entire city, links to the lower R-tree level, links to the 2D GIS (optional), no CAD data.
Level 1: One district, links, low resolution CAD data.
Level 2: One city block, links, medium resolution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

Culling is used to pre-select the data base content by visibility conditions. In the case of the perspective visualization it is the intersection of the data with the view frustum or in the case of antenna signal strength propagation the electromagnetic cone of the antenna. This method can also be used to distinguish between different levels of detail.

Levels of detail have already been mentioned and are used rigorously. A sequence of CAD models (vector data) of different resolution and quality (different levels of detail) for each object is prepared and stored in the data base. The payload for simulation and visualization is now scaleable by choosing a distinct level of detail for an object, e.g. in combination with the culling mechanism.

Dynamic loading has to be applied if the entire data base content of a large city shall be available. Then 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 fast data retrieval mechanism to provide users with the necessary subset of data just in time.

6.6 The Vienna Walk-through System

The Vienna Walkthrough System was designed and implemented by Kofler (1998). The purpose of this system was to manage the entire geometry of the city of Vienna for interactive visualization. The entire data set contains 20,000 building blocks, acquired by traditional photogrammetric methods (see Section 4). These data have been transferred into a completely three dimensional data structure, different levels of detail have been created and organized via the LoD-R-tree data structure. This was implemented on a Silicon Graphics Indigo-2 workstation and High-Impact graphics board (cf. Fig.4).

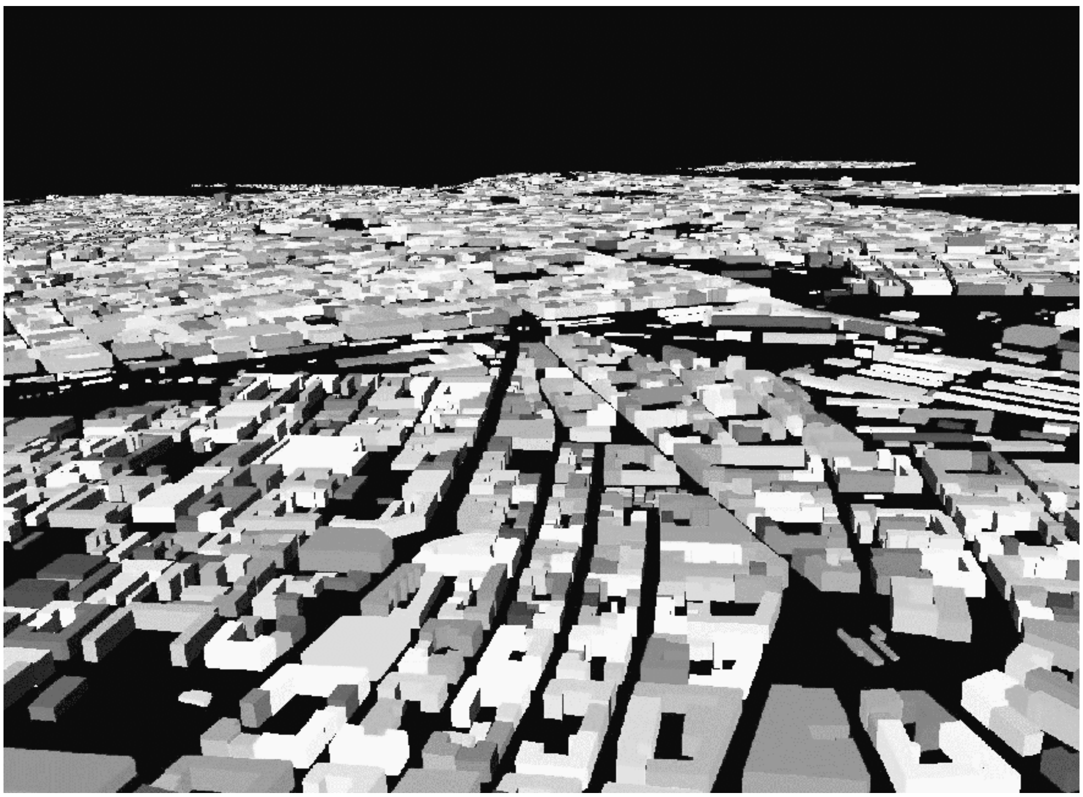

Figure 4: The Vienna walk trough system, as it is implemented on a Silicon Graphics desktop workstation. The navigation during interactive visualization is possible at a frame rate of appr. 15 frames/sec.

7. CONCLUSION

Three-dimensional data structures of urban areas are urgently needed for many reasons. The most relevant initial use derives from the needs of the mobile telecommunication industry. During the last years we have observed an increasing interest in these data for that specific application. Since they were not available on the market, three dimensional data of city structures had to be produced on behalf of the telecommunication companies. Most of the data have been created manually using analytical or digital photogrammetric methods. Non-traditional automatic methods based on image analysis and pattern recognition had not yet been developed sufficiently to replace the labor intensive manual procedures. We described a European project in which 60 to 80 buildings were manually collected per hour. We expect that increasing competitve pressures among telecom providers to offer “perfect” reception, and newer technologies, will further increase the demands on detail, resolution and accuracy of urban 3-D data.

In order to make these novel data available for other users one needs appropriate tools to manage such 3-D geometric information. We have developed and shown examples of methods to organize the data by exploiting an object oriented data base management system and by adding methods to visualize such large data base contents of entire cities in support of further interaction.

LITERATURE

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