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Models of Urban Areas for Line-of-Sight Analyses

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ABSTRACT

Three-dimensional computer models of urban areas have become a standard offering of photogrammetric data providers. Initial drivers for the creation of such data have been defense organizations to support military operations in urban terrain, and the Telecom industry in their optimization of certain communications networks that depend on line-of-sight analyses in urban environments.

The issues today are less the principles of image information extraction, but instead increases in productivity to achieve reductions of data costs, the organization and manipulation of large sets of data, quality control and data updating.

We report on an operational system to develop 3-D models of urban areas and describe some of the current problems one is faced with when an entire city's model needs to be manipulated. We present our views on the expected utility of upcoming 1-m optical satellite images as a source for such data bases.

1. INTRODUCTION

The creation of a fully 3-dimensional computer model of urban building assemblies may have been a novelty in 1995 (Gruber et al., 1995; Grün et al, 1995), but it is rapidly becoming a well-understood extension of 2-dimensional GIS data collection. The issues are less the data sets themselves as they are the reduction of cost to create the data automatically (Henricsson et al., 1996), and the ease with which large data sets can be manipulated with unaided computers devoid of special hardware (Gruber et al., 1997; Kofler et al., 1996).

Two applications seem to dominate the initial drive towards building models: the hunger of the Telecom industry for data to better plan wireless networks in cities, and the military's need in support of operations in urban terrain. Other uses are less prevalent, although there are numerous secondary drivers for such data bases, such as disaster preparedness, urban planning, architectural visualization or tourism.

Photogrammetric interest focuses on the creation of data and ensuring that its quality is high (Strat, 1997; Leberl et al., 1998; Lukes, 1999). This will include visualizing the 3-D data and relating them to the sources from which they were extracted. "Quality" refers to the absence of blunders, the meeting of well-defined geometric accuracy specifications and the completeness of the data sets. Typical primary objects of interest are buildings, trees and other visual obstructions. Current interest is for data with an accuracy of ± 1 m in the three cardinal directions. This excludes considerations for building details such as windows, doors, chimneys, skylights and the like, and instead is satisfied with the coarse building boxes that represent the major visual obstructions.

"Line-of-Sight" analyses are the applications that rely most heavily on such 3D urban building data. Broadband wireless access or BWA represents a wireless alternative to fiber-optic communications lines. Data are being transferred by microwaves from antenna to antenna. These are set up on rooftops in a manner that maximizes each antenna's viewing area (Figure 1.1). At frequencies of more than 2 GHz and up to 35 GHz, the corresponding antennas need to have an unobstructed line-of-sight. The most demanding applications for urban 3D geo-data are in those cases where such lines of sight need to be optimized in a computer, relying totally on the accuracy and completeness of the data.

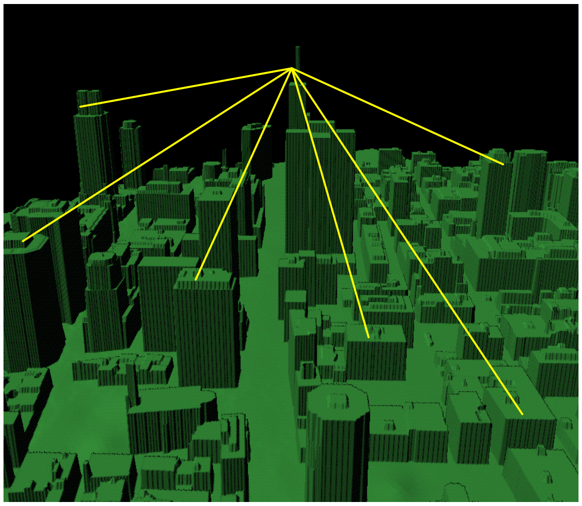


Figure 1.1: Concept of Local Multipoint Distribution Systems LMDS, the most demanding driver for 3D geo-data of urban areas. This technology is at times referred to as "wireless fiber optics", as illustrated here with the central area of Montreal, Place Ville Marie.

In the intense competition between different technologies to connect offices, broadband wireless access by means of Local Multipoint Distribution Systems LMDS now competes with not only fiber-optic lines, but also with satellite-based services which suffer less from visual obstructions. Lower cost of entry and full scalability are the great advantages of LMDS technology and drive the interest in the most detailed and accurate 3D models of cities. And in addition to supporting the radio frequency analyses for the optimum set-up of such communications networks, there is also the support that the geo-data provide to the efforts of selling the services, and of supporting the customers when decisions have to be made about the optimum link of a building into a network, and about the connectivity for a given address.

2. PRODUCING 3-D DATA

2.1 Requirements for Data Extraction Technology

A great variety of techniques exists to convert various data sources into useful entries in a 3D geo-data base. Typical source material is aerial photography or LIDAR, either with or without the use of a 2-dimensional GIS as the basis on which the third dimension is built, and either with conventional positioning techniques or with positioning by means of GPS and IMUs; in fact, LIDAR simply requires that GPS/IMU-support be provided, or the data are not useable. In this paper we focus on aerial and space photography, and we thereby ignore the role of LIDAR in the urban 3D modeling application.

Different methods of data acquisition from images are presented among others by Englert and Gülch (1996), Henricsson et al. (1996), Grün (1996) and Lang and Förstner (1996). The fusion of different source data, namely existing data from the two dimensional geographic information system (2D GIS) and data from new sensors (Laser Range Systems) are presented by Haala (1994) and Maitre (1996).

2.2 Photo Scales and Overlaps

One issue is the proper scale of aerial photography which naturally presents the question of the usefulness of 1-m optical satellite imagery as a source for such building data. Such a specification of source material may be easy to define, yet in many cases the time pressures to arrive at some useful data will not permit the acquisition of tailor-made aerial photographs. Instead, one will need to rely on pre-existing photography at the typical 60%-forward and 30%-side-laps of the industry, and the issue is then what are the best methods for producing 3D geo-data when the actual photo scale and overlap configurations differ from the ideal arrangement.

Ideally one will want to select an overlap to support the automatic DEM-extraction without the notorious problems of hidden surfaces and effects of vertical discontinuities around buildings. This would suggest the increase of the overlaps to perhaps 80% forward and 60% sidewards or 70% forward and 55% sidewards. It would lead to automated matching being based on image pairs that are more similar to one another, and to a strengthening of the DEM solution by redundancies. However, the improvement of automated information extraction may not be sufficiently compensating for the increase in cost of processing more imagery. After all, 80/60 overlaps produce 4 times the number of photos than 60/30 will.

2.3 Achieving Low Data Cost

Another issue is the achievement of the minimum cost in creating data at a given specification. The typical process currently is based on the use of analytical plotters and the manual collection of polygons describing the details of buildings. This is not a particularly inexpensive nor a very creative process. At issue is the ability of reducing the number of manual actions in the data collection by automation, to reduce the level of training for the manual work by avoiding complexity and skill requirements in decision making by the human operator, and to avoid the use of specialized and expensive equipment that will limit the amount of data that can be created in a given operation.

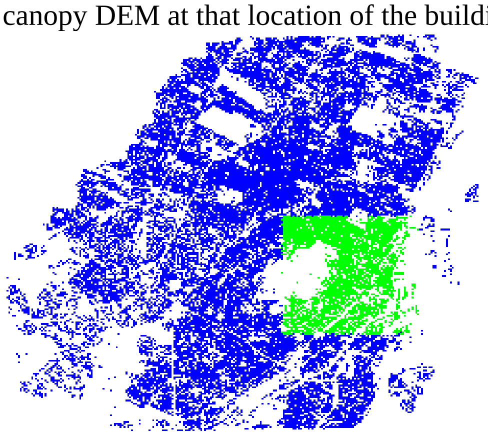
Some principles of cost control can be seen in a process of data extraction that is "scalable", and that can be adjusted to the level of productivity that is needed. A photogrammetric process will be "scalable" if it is possible to add staff quickly, and reassign it when the demand flattens out. This is only feasible with a process that does not require massive training nor a significant increase in assets which would idle as demand reduces. A software-oriented process using low cost personal computers is more likely to meet such requirements than the traditional analytical plotter approach would promise. Spradley and Welch (1999) recently presented their production system based on a non-stereo approach.

Cost is also held in check if the data product can be "scaled" to the specific needs of an application. These needs differ as a function of e.g. the frequency used in the deployment of a wireless Telecom system. Installing micro-cells in street canyons for a cellular telephone system requires far less detail and accuracy than the strict line-of-sight LMDS technology. There must thus be variations of the data creation technology that can produce lower accuracy data when these are needed, yet also scale up to accurate data otherwise.

2.4 An Example

An illustration of some of the previous discussion points follows. The metro-area of Montreal covers almost 5,000 sqkm and has about 1.3 million households. However, while nominally a single wireless Telecom license may be defined for the entire area, only the most densely populated 300 sqkm or so may be developed by the Telecom industry. Figure 2.1 illustrates the vastness of a data set created for a Telecom application interested in a 300 sqkm sub-region surrounding the core of the metro area. This includes 250,000 buildings, often at a density of 1000 buildings per sqkm. In a 32-times enlargement shown in Fig. 2.1 (middle) one can finally discern the individual footprints of each building. But to fully appreciate the details of a single, more complex building, an enlargement of 128 is needed (Figure 2.1, below), or the detail of a complex dowtown structure like a cathedral (Figure 2.2 and 2.3).

Figures 2.4 through 2.6 tell the story of the data components and deliverable data product. While the buildings are the focus of such urban data bases, the spaces between buildings need to be described as well. Customarily this is being accomplished by combining the result of a background "*canopy DEM*" (Fig. 2.4, 2.5) with the 3D shapes of buildings that replace the canopy DEM at that location of the building.



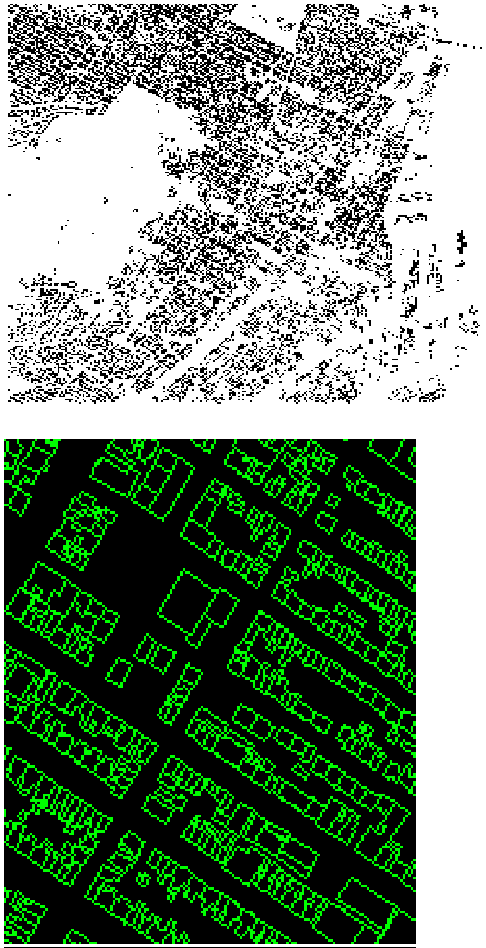


Figure 2.1 Appreciating the vast data quantities for a metropolitan region. Shown is an area of 300 sqkm of Montreal, Quebec (above). Extracted building footprints are plotted. The detail (middle) is 32 times enlarged, and the details of an individual building are illustrated in the lower image at a 120 x enlargement

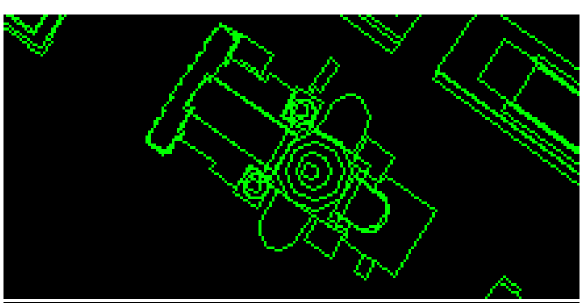


Figure 2.2: Detail of a complex building in dowtown Montreal.

Figure 2.3: Photographic detail of the building in Figure 2.2

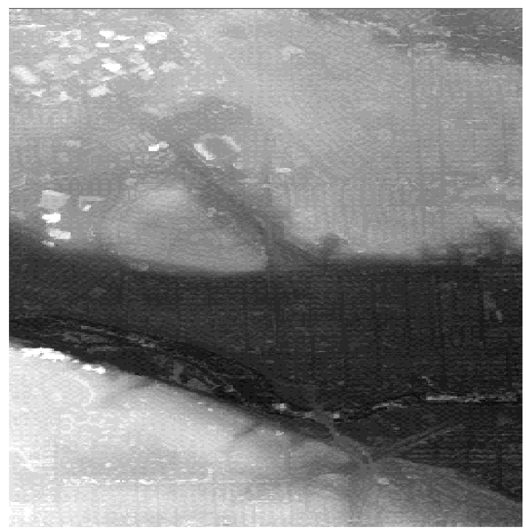


Figure 2.4: A ‘canopy” DEM of Montreal, encoding “height” as brightness

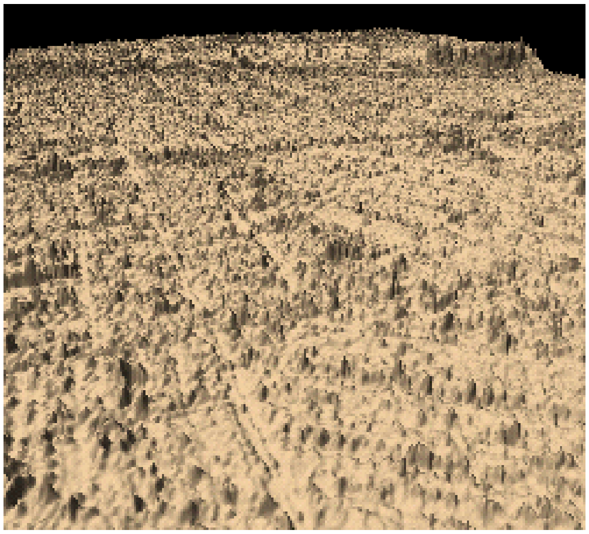


Figure 2.5: Perspective view of the canopy DEM in Fig. 2.4 of Montreal.

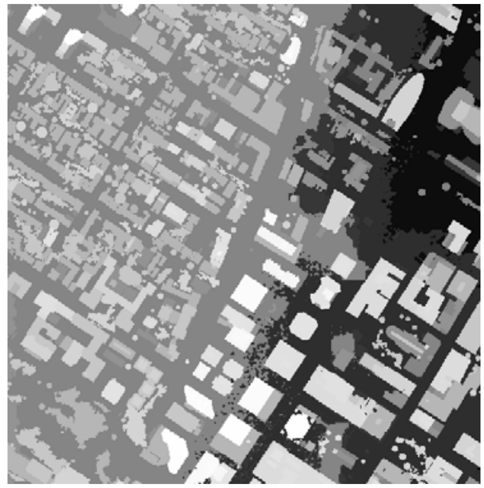
The raster data are at times called "flooded grid presentation" and is geometrically identical to the vector data which in many cases are needed in the applications since they present the topological descriptions of buildings. An individual building will in this case be described by its footprint at the level of the ground or "bald Earth" and the roof detail visible from above.

3. TREES

The line-of-sight requirement of urban geo-data demands that visual obstructions other than buildings be modeled as well. This concerns trees, which will in some cases be modeled by means of tree symbols at the location of a tree, and at other times be described by means of polygons, in particular when groups of trees are concerned. Automated classifications based on texture are applied to image areas not defined as buildings. The classification result is manually augmented and edited. If available, the classification will consider color as well.

4. ADDRESSES

The use of the geo-data in the Telecom application is not restricted to the geometry-based engineering aspects of laying out so-called hubs. There are the very important demographic aspects of the network plan as well. A hub needs to "see" the most valuable buildings. This will need the support of a business data base that is to be connected to the geometric data. The link is being established by addresses (Figure 4.1). Addresses of course can serve not only as a useful data layer in itself, but they also represent a quality assurance tool. Buildings need to have addresses, and addresses typically should have buildings associated with them, unless they describe empty parcels of land.



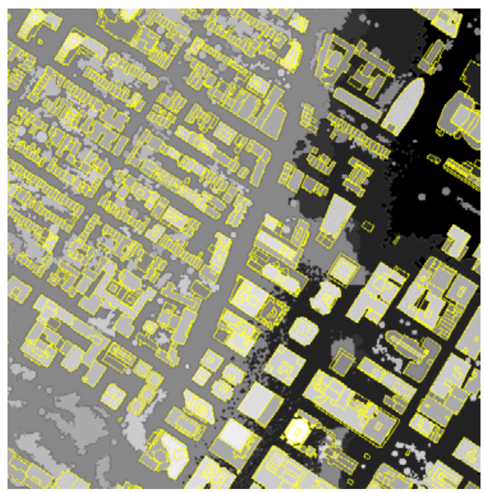
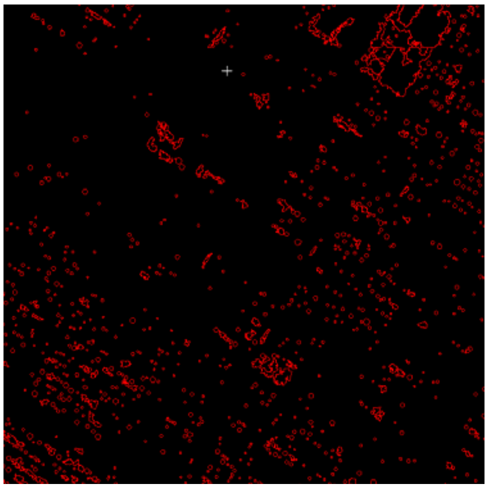


Figure 2.6: Deliverables consisting of a *Canopy DE*M plus buildings (above), augmented by vectors of the buildings (below). Note that in this example, all buildings are individually mapped, whereas more commonly only commercial buildings are individually mapped and residential buildings are only shown by means of the canopy DEM.

But addresses have yet another effect on the geometric data: they extend their life beyond the setup of a Telecom network. In fact, all during the operation of a wireless broadband access network, it is the combination of geometric and demographic data which support the marketing, selling and administration of such a network, by documenting the signal strength at each building, and for each address and customer, be this a potential customer one will want to recruit, or an existing customer for whom the signal strength needs to be maintained at satisfactory levels.



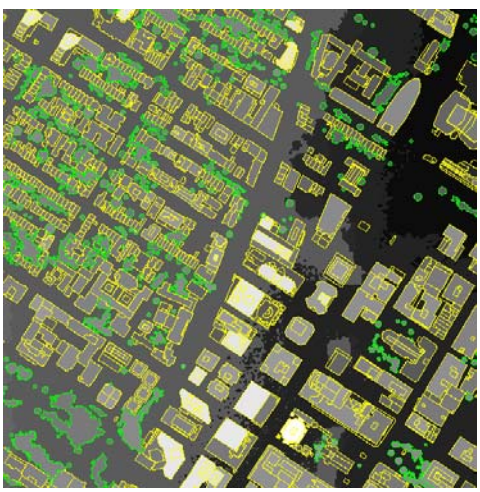


Figure 3.1: Trees in a separate data layer (above) and added into the deliverable "flooded grid" (below). Usually, trees are only represented as part of the canopy DEM, but in the current example, trees are modeled separately and represent a unique information layer.

5. DATA MANIPULATION

The example of an urban data model of 250,000 buildings as used here presents an interesting challenge to anyone attempting to view the data, roam in it, change it, and create visualizations from it. Of course this is on one hand an issue for the application of the data to deal with. But it also is an issue within the data creation work flow when various quality assurance and editing functions need to cope with oftentimes extra-ordinarily large quantities of visual data.

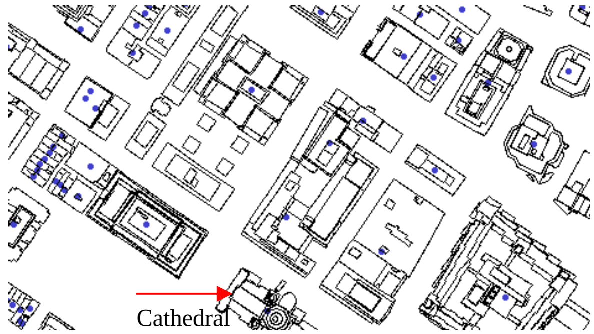


Figure 4.1 Adding addresses to the 3D urban building data for the example of the geometric data of Montreal. Note the complex shape of the downtown cathedral in the lower center of the data segment. Addresses are associated with positions marked by points. Buildings may have multiple addresses, and some addresses may have no buildings associated with them.

The Telecom application has yet to develop an appetite for a description of the materials that exist in the urban scene. It will be not until then that the geometric and demographic data of interest today will be augmented by texture data as illustrated in Fig. 5.1 But first indications exist that surface properties of buildings would be of interest to analyses using recent RF engineering software. After all, reflections are a major issue in determining the signal paths between hubs and customer sites, particularly when one envisions a future with multiple competing networks using similar frequencies at a not too distant point in time when urban roofs will be populated with data and Internet access devices of competing vendors.

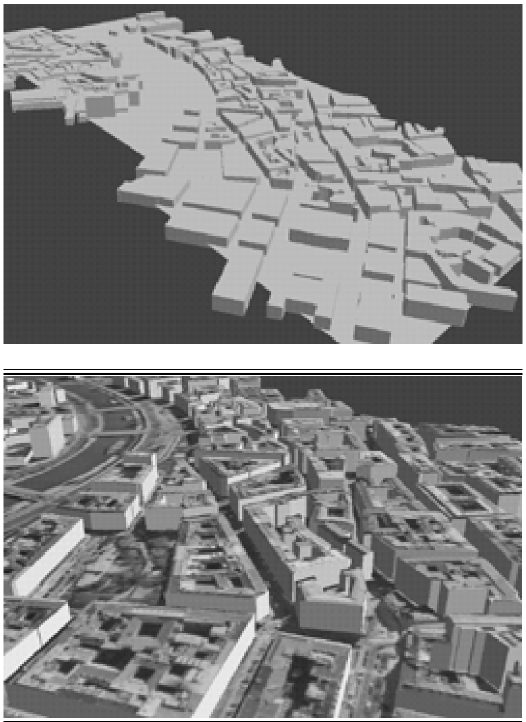


Figure 5.1 Draping the photo texture over the 3D geometry (above) can support quality control, and result in a product that presents the material properties at each surface by means of the gray values of a photograph (below).

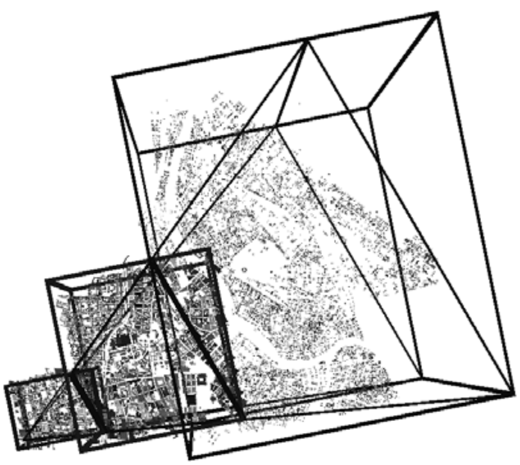


Figure 5.2 Visualization of a large data set of an entire city. The view frustum is subdivided into three areas of different levels of detail used to organize the loading of the three dimensional data base content, accelerating the image generation on an unaided SGI-Impact by a factor between 50 and 100.

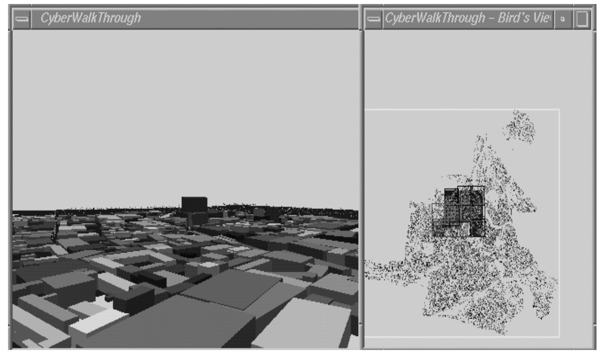


Figure 5.3: The Cyber-Walkthrough system is designed to visualize large urban 3D data sets while maintianing the ability for an interactive manipulation (Example: City of Vienna).

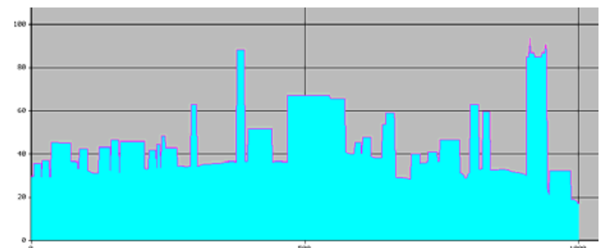


Figure 5.4 Assessing the line-of-sight between any two points in the raster data. Example is from Vancouver.

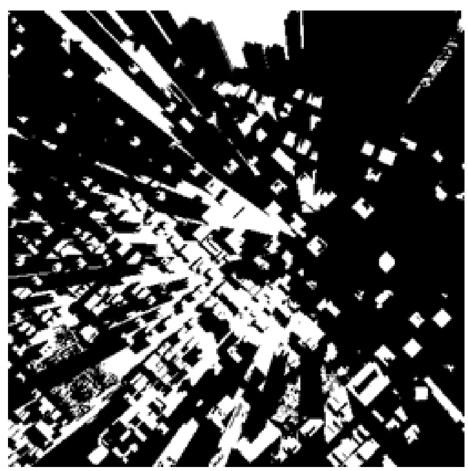


Figure 5.5 Computing the visible areas from the position of a proposed "hub". This can be converted to signal strength in an area as a result of placing a a mobile viewing position and changing viewing resolution data system that supports the quick search, retrieval and rendering of the data using typical LMDS hub on top of a building. Example is from Vancouver.

The concern for the ability to manipulate large sets of geometric and texture data exists for some time. Avoiding special hardware is a desire, and can be achieved by smart data organization schemes. Kofler et al. (1996) have described a data structure that they called LoD/R-Tree (Level-of-Detail in combination with a 3-dimensional extension of the traditional 2D Rectangular Tree structure). Figure 5.2 illustrates the basic idea. The data base is in this case organized into a hierarchical multi-resolution data system that supports the quick search, retrieval and rendering of the data using a mobile viewing position and changing viewing direction. Figure 5.3 illustrates the dynamics of such a data structure that supports motion and therefore increases speed of data retrieval and rendering.

The most common application of urban 3D building data bases currently is in the computation of lines-of-sight. First experiences with three dimenional urban data for network planning are reported in Loffet (1996) and Siebe (1996).

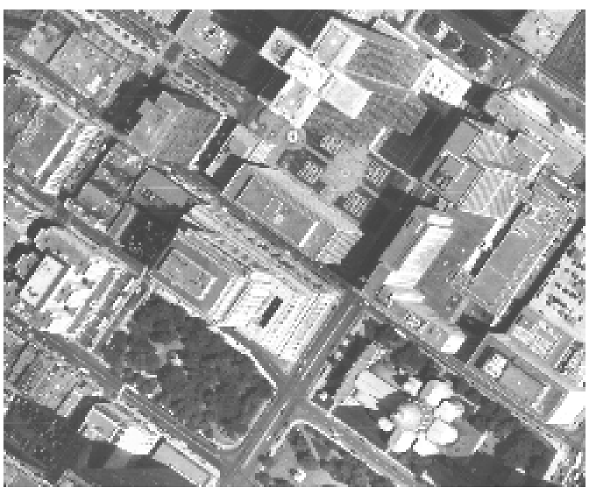


Figure 6.1: Segment of photo coverage at resolution of 0.9 m per pixel, simulating a high resolution optical space image. It should be possible to extract commercial buildings from such imagery.

Figure 5.4 illustrates the idea. The attenuation of a signal along such a line-of-sight leads to a map of signal strength (Fig. 5.5). This can now be intersected in typical GIS-fashion with information about business demographics to assess a figure of merit for each proposed LMDS hub position.

6. SATELLITE IMAGES

The presumed accuracy needs of data applications in such urban geo-data bases are often at ± 1 meter in x, y and z (standard deviation). Since the SPOT stereo DEMs based on panchromatic SPOT pixels with a diameter of 10 m are often quoted with an accuracy better than a pixel, namely at ± 6 meters or so, the question is being asked often about the applicability of highly anticipated space-based 1 meter high resolution optical imagery to the creation of urban geo-data bases. If a 10-m-SPOT can produce ± 6 m errors in elevations, can a 1-m satellite sensor produce building models with only ± 0.6 meter uncertainty?

This discussion lends itself of course to a dry analysis of photogrammetric error propagation. Essentially, a 1-m pixel from space should be analogous to a 20 µm pixel from an aerial photo taken at scale 1:50,000. In the event of a wide angle camera, this would represent a flying height of 7,500 meters, and an elevation accuracy of better than ± 1 m if the photogrammetric process provides an accuracy of 1 part in 10,000.

7. OUTLOOK

The introduction of wireless communications services has of course by now a very long tradition. But it certainly has gained considerable momentum with the advent of cellular telephony. At frequencies in the sub-GHz range, going up to perhaps 1.8 GHz, terrain data requirements were fairly modest and were met with digitized map contours, public domain digital elevation models, augmented by satellite remote sensing image classifications to create so-called "*clutter maps*" to describe land use. The Telecom industry became used to data costs in the rage of perhaps as little as 2 to 5 cents per sqkm for such data.

The transition to line-of-sight analyses for much higher frequency telecommunication has resulted in a "sticker shock" in the Telecom industry, since urban 3D building models simply do not exist, and certainly are not available in some nearly free public domain data bases. Instead, such data must be created on demand and under contract to the Telecom customer. This has held back the wide spread application of such 3D data in the Telecom industry, and has kept that industry's engineers to continue their reliance on old-fashioned pre-LMDS RF-engineering approaches with binoculars on roof tops to avoid the use of geo-data for planning.

However, as the planning tools of RF engineering vendors improve, the Telecom application increasingly looks beyond the strict use of data for RF-design work, and uses it even more in the marketing of the new wireless broadband Telecom services. As a result the industry has begun to appreciate the value contributed by accurate 3D building data. This now causes the widespread emergence of such data bases of every major metropolis.

Independently, the defense application is another driver for the advent of 3D urban building models, and in this application the need has emerged to improve the data detail by means of photographic texture modeling for added realism in simulations and training. And these developments will benefit also the public functions of urban planning, architecture, disaster preparedness, tourism and entertainment.

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