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Advances in Built-Up Area 3D GIS Data for Telecommunications

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ABSTRACT

We report on our work to efficiently create data bases of urban areas for use in the telecommunications industry. These data bases may consist of a Bald Earth Digital Elevation Model (DEM), augmented by the vertical objects on top of the DEM. Such vertical structures are the individual buildings, trees and other obstructions to the line-of-sight between any two points in a city. The needs of telecommunications projects may vary widely. They may range from the cursory digital surface model DSM, which is the reflective surface seen from the air or from space, to a complete 3-dimensional GIS data base at very high 1 meter detail and ± 1 meter accuracy in which even each individual address of a business or household can be represented and retrieved, and may rely on simple raster-files or more complex 3D vector data. The detail and accuracy depend to a great extent on the radio frequencies and technologies in use, and therefore on the sensitivity of a telecommunications system to any obstacles that may exist between a transmitting and a receiving antenna. Telecommunications is pioneering the use of 3D urban data, but other applications are emerging for the pending transition from the traditional 2D GIS to the 3D CyberCity.

1. INTRODUCTION

Wireless telephone systems grow, more competition comes into existence, a range of technologies being implemented, and a wider range of the electromagnetic spectrum is being used. As a result the needed densities and accuracies of digital elevation models (DEMs) used in telecommunications change. These DEMs with their thematic surface data are used for planning the development and management of wireless networks. In urban areas, intervisibility between any two points is defined by buildings, vegetation and other objects. As a result, the quality of the wireless telephone signals can only be accurately predicted and understood if dense urban areas are accurately modeled. Improvement of the signal quality may be based on the use of so-called micro-cells for an urban cellular telephone network. But the effect of a new micro-cell can only be optimized with the help of accurate and detailed terrain information. The data demands grow as shorter wavelengths of the electromagnetic spectrum get used, and as competitive pressures increase the demand for high quality signals.

A challenge is also presented by the needs of wireless Local Multi-point Distribution Systems (LMDS) which employ microwave links from each individual building to some central locations. This operates on the basis of lines-of-sight and, as a result, needs accurate data about any obstructions to the intervisibility between any two points. Of course, the radio frequencies employed by the LMDS-type telecommunications provider is also defining the need for detail and accuracy of the terrain data. The computer model of buildings, and thus the entire idea of a CyberCity, is moving center stage in these applications.

Modeling buildings of urban areas in a computer has long been a challenge for photogrammetry and image analysis, and in fact has been the topic of many years of academic research as part of DARPA's Image Understanding program (See Proceedings of the Image Understanding Workshops, most recently in Strat 1997; and similar European programs as described in conference proceedings edited by Grün et al., 1995 and 1997; and by Leberl et al., 1998). Manual, semi-automated and automated techniques have been proposed to acquire such data efficiently. Both single images as well as stereo image pairs have been or are being used as the source material from which to extract the desired building data. A rich collection of research efforts exists from which to draw experiences to meet current operational requirements. These efforts seek to replace the traditional stereo-photogrammetric methods by innovative non-traditional alternatives.

We demonstrate results from an automated process based on strips and blocks of overlapping aerial photography. These images are being scanned, processed photogrammetrically and submitted to an automated extraction of surface elevations, including buildings and trees. Manual interventions are employed economically to post-process the automatically acquired data, and to provide inputs to the automated procedures. We show that automated methods can produce building data of sufficient accuracy and completeness to serve a wide range of needs in telecommunications. Detail and geometric resolutions of 1 meter, and accuracies better than ±1 meter are being achieved routinely.

Telecommunications needs can thus serve as a driver to broaden the existing 2-dimensional GIS into fully 3-dimensional data systems, and into the idea of the CyberCity as a computer model of a city's structures for a virtual reality approach to urban cartography and mapping (Gruber et al., 1995; Kofler et al., 1996).

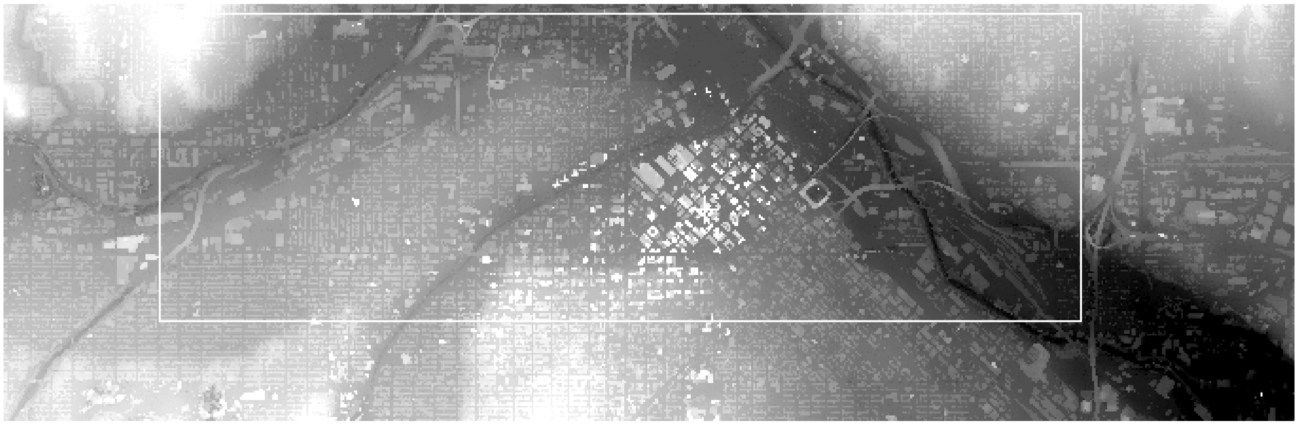
The traditionally held view sees as only reasonable source for such 3D urban data the optical photograph, perhaps some LIDAR laser scanning But we will provide a glimpse of the usefulness of radar images at their increasing geometric resolution, their ability to interferometrically observe terrain elevations, and their ability for multi-pass repeat imaging 24 hours a day and independent of the weather. As a result it becomes increasingly interesting to map urban environments using microwave imagery (Bickel et al., 1997, Burkhart et al. , 1996).

2. THE DIGITAL SURFACE MODEL AND THE BALD EARTH

Digital Elevation Models (DEMs) are of course a traditional topic of photogrammetric technology, and many procedures exist today to create such digital data in a computer from scanned aerial photography and image matching (for a review see Förstner, 1992). Figure 1 presents the segment of an aerial photography coverage of a region in Denver, covering about 7 kms x 3 kms. Such photography lends itself well as an input to a softcopy photogrammetric process and to the automated extraction of a Digital Surface Model (DSM) of the reflective surfaces. A stereo-correlation procedure will develop a dense number of match points which combine with the camera orientation into a raster DSM with accuracies that depend on the scale and quality of the aerial imagery. The example in Figure 1 is at an accuracy better than ± 1 meter.

Figure 1: Aerial photography coverage of a region in Denver. The area covered is 7 kms x 3 kms. Such photography is easily available from routine municipal photo missions, or for specific projects, and represents only a small part of the overall project expense to create a 3-D model of a city.

Figure 2: The Digital Surface Model, automatically derived from the images of the type in Figure 1, has postings of its elevation data at 1 m intervals and covers 13 km x 4 km. The coverage of Figure 1 is marked.



The resulting DSM is presented in Figure 2. Note that such data can be created entirely automatically and with scant manual intervention.

The task now is to separate out the vertical objects and present them apart from the so-called Bald Earth. Figure 3 illustrates the basic concept. Various techniques exist to define vertical objects and to "filter" them from the DSM, thereby creating both a Bald Earth Digital Elevation Model (DEM) and candidate vertical objects.

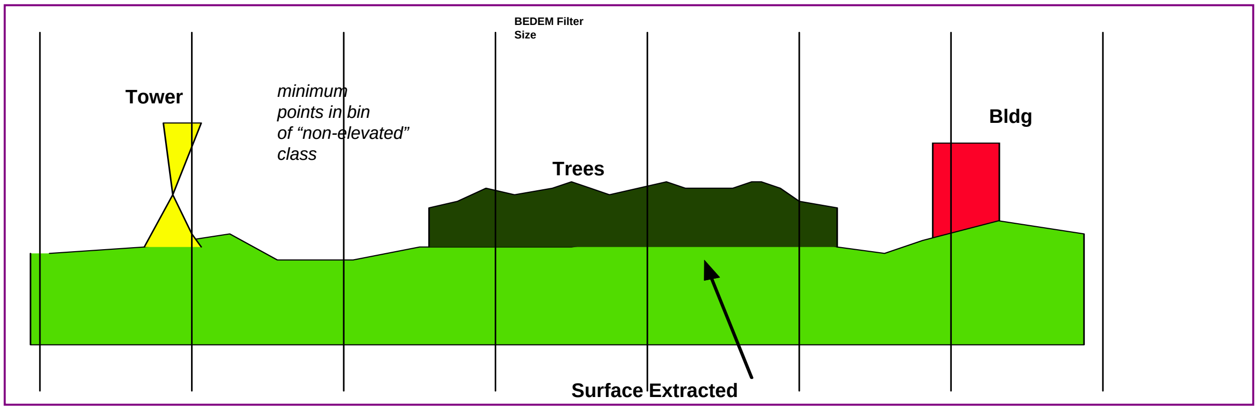


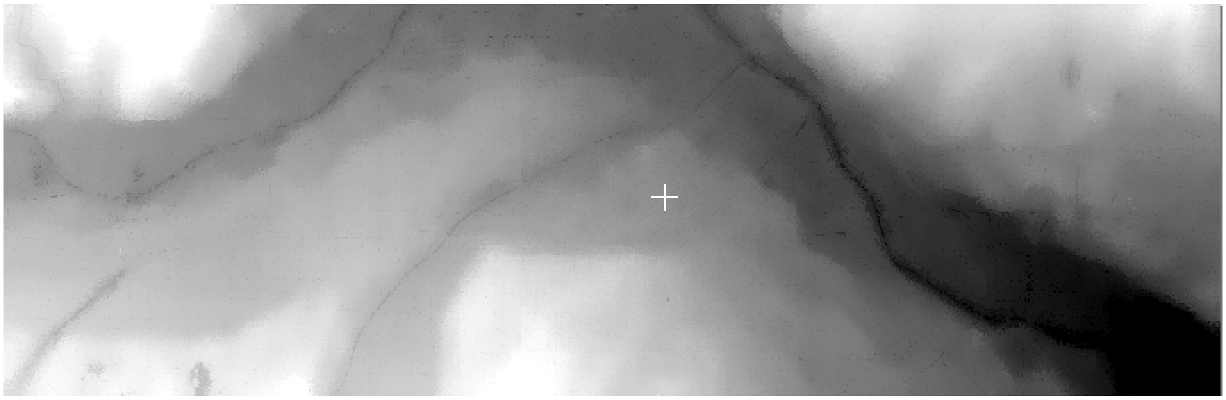
Figure 3: The concept of a Bald Earth DEM (Courtesy R. Carande).

Figure 4 is the DEM that resulted from the source images in Figure 1, again obtained from a fully automated process.

Of course, DEMs can also be created from novel interferometric SAR images. In that case, the terrain elevations are not computed from a comparison of images taken along two flight lines, but instead are directly observed along a single aerial or satellite flight path. This is thus analogous to an altimetric observation of terrain. Figure 5 presents an example of a DSM from SAR-interferometry, as well as a Bald Earth DEM, of another area extending about 1.9 kms x 1.4 kms. The accuracy of such DEMs is in the range of about ± 1.5 meters using SAR image sources with pixel sizes at 3 meters (Mercer, 1998). The accuracies will be better than those shown in the data of Figure 5 if the SAR images are obtained with smaller pixels, say at 1 m or even 1 foot per pixel.

Figure 4: Example of (a) a Bald Earth DEM extracted automatically from the DSM in Figure 2 and (b) the separate vertical objects, covering an area of 13 km x 4 km.

(a) Bald Earth



(b) Vertical Objects Only

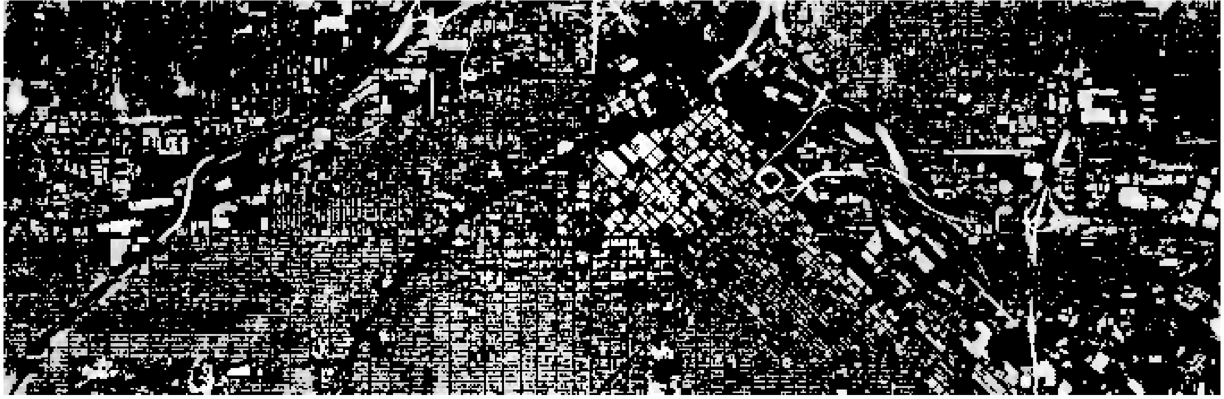
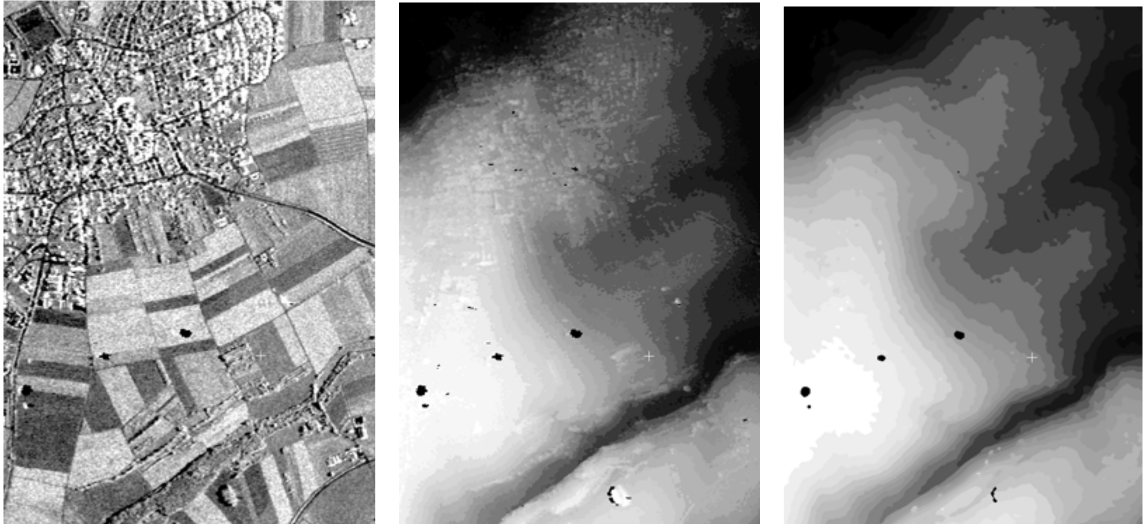


Figure 5: A DSM and Bald Earth DEM obtained from SAR-interferometric radar images. Area covered is 1.9 kms x 1.4 kms. Source material is the IFSARE/Star3i radar system operated by Intermap-Calgary at a resolution of 2.5 m/pixel. (a) is the SAR image, (b) the Digital Surface Model with vegetation and transmission towers, (c) is the bald Earth DEM.

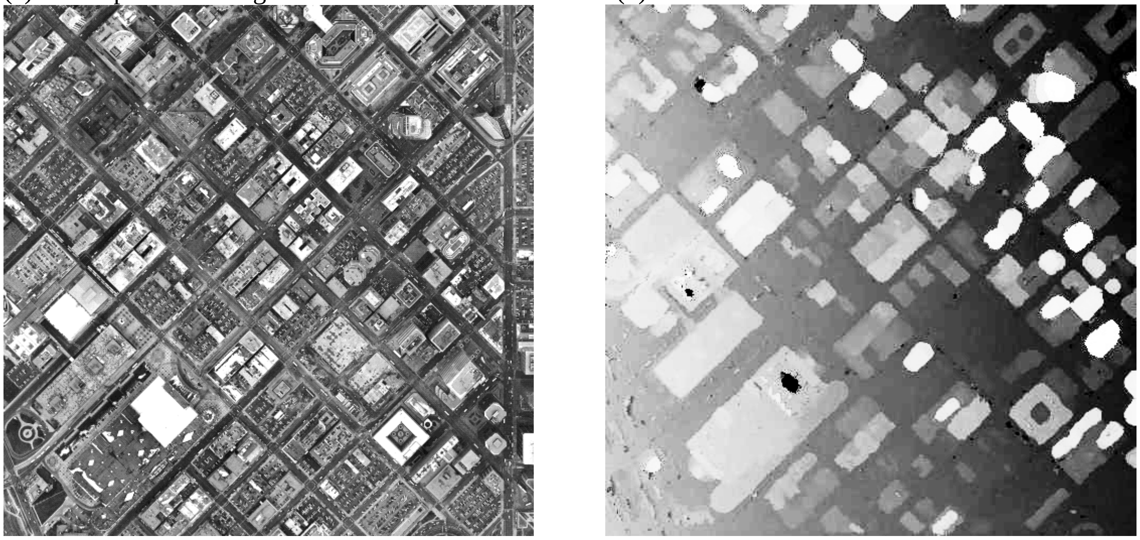


(a) (b) (c)

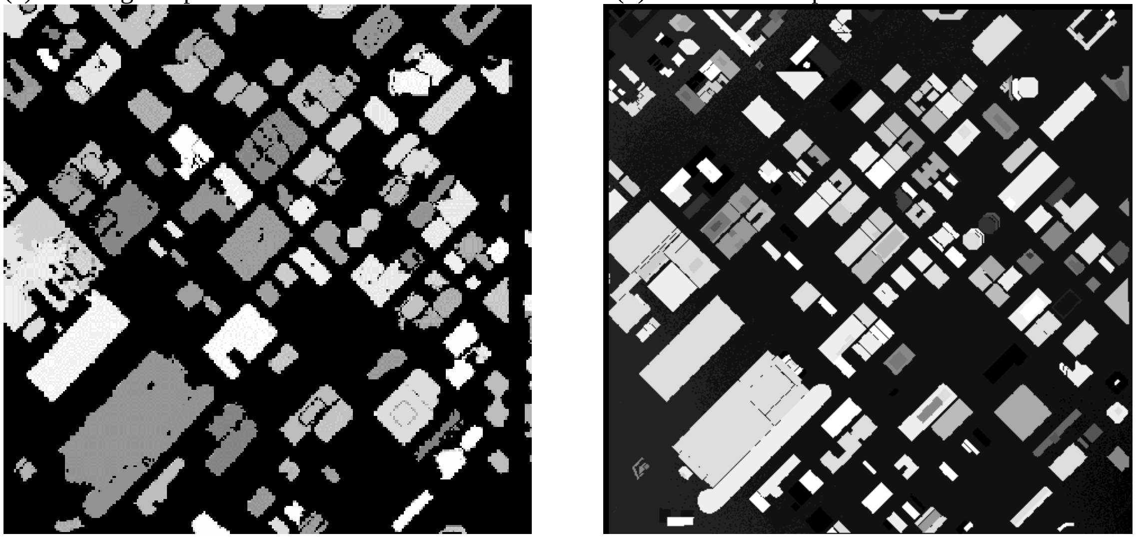
3. VERTICAL OBJECTS

The telecommunications application needs of course information about the terrain elevations, but this is only part of the required geometric information. The modeling software for the lines-of-sight and radio-frequency propagation often needs the vertical objects on top of the Earth’s surface as well. The task exists thus of refining the candidate vertical objects ob-tained from the image matching (or interferometric or altimetric) observations. Here the photogrammetric technology pool is largely undeveloped. The traditional view in the field is to collect vertical objects manually. The costs associ-ated with manual collection are, however, rather high when considering it in terms of building a telecommunications network for an urban area, but also when other applications are considered, be they military or municipal.

Figure 6: Illustrating a downtown DEM with highrise buildings. Automated processes are being applied to the DSM to extract candidate vertical objects. (a) is part of an aerial photograph of downtown Denver; (b) is the DEM as extracted from the photography. From this, footprints are being computed for the vertical objects as shown in (c), and subsequently refined; (d) presents manually derived footprints for comparison..


(a) Aerial photo coverage

(b) DEM

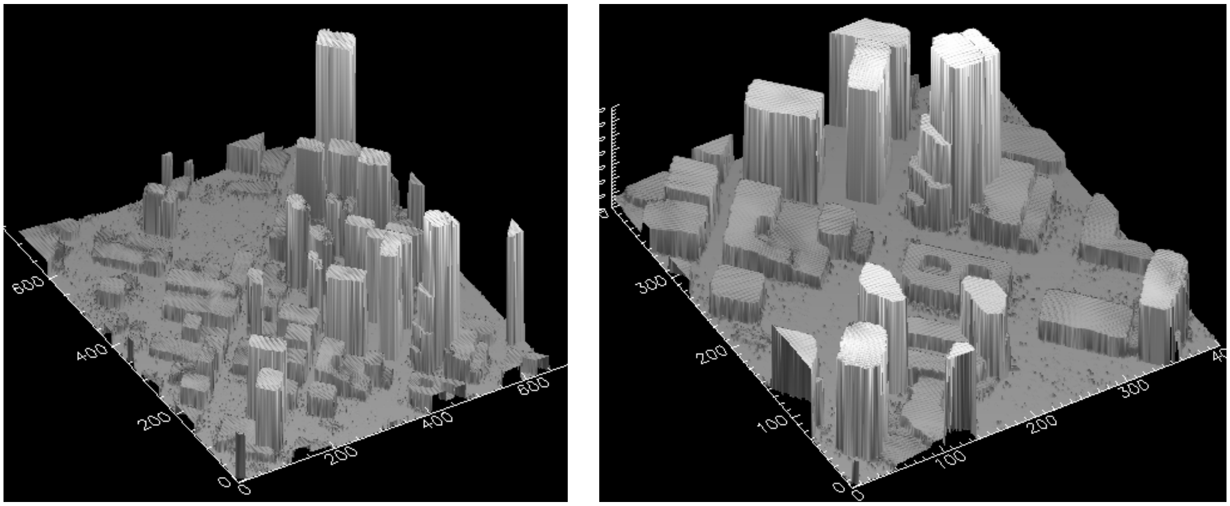

(c) Building footprints

(d) Reference footprints

Figure 7: Rendering the result of the Denver raw building data (a) as extracted automatically and (b) in a close-up view.

(a)

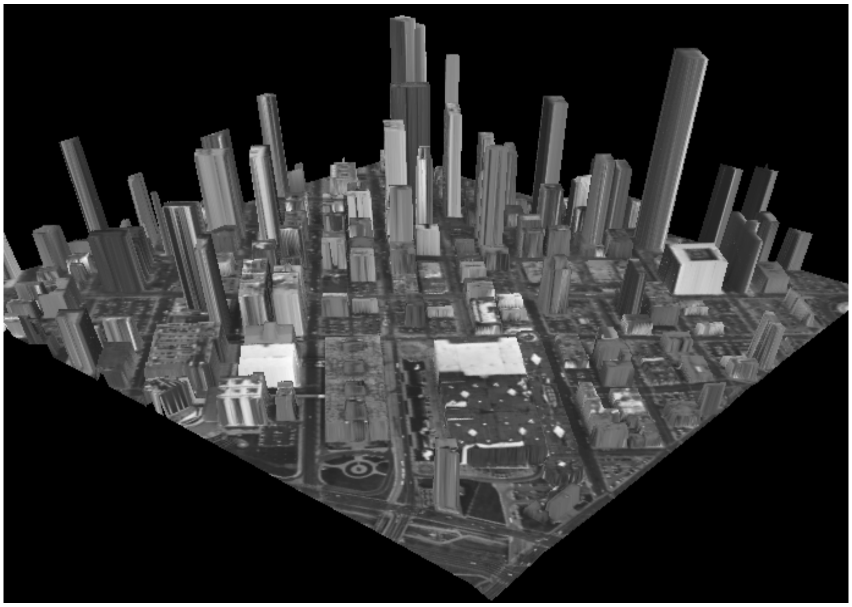
(b)



At issue is the reduction of cost for the extraction of buildings and other vertical objects, and of creating geometric models of each building in a manner that is amenable to an association with a city's telephone directory and its household addresses. Figure 6 illustrates for the Denver site the transition from the automatically extracted DSM to the identification of individual buildings, and from there to the shapes of these buildings.

The outcome of such fully automated procedures needs to be subjected to some manual and interactive quality control. In order to avoid the expense of the manual process "creeping" in via the detour of quality control and error fixing, the manual process needs to be intelligently concatenated with the computer procedures. Manual inputs need to guide automated procedures and vice-versa. The result is a completed urban building data base as shown in Figures 7 and 8, one just presenting the building's geometries, the other refining the visual presentation by means of photo-texture.

Figure 8: Building height model augmented with the photographic texture from the aerial imagery.



4. THE 3-DIMENSIONAL GIS: CYBERCITIES

The sharpening telecommunications requirement for increased detail and accuracy in its urban source data for RF-propagation modeling and line-of-sight analyses coincides with a generally increasing public interest in the transition from the traditional 2-dimensional GIS into a fully 3-dimensional data structure. At the end we find the vision of the CyberCity, a photo-realistic 3-dimensional model of an urban environment. This is the combination of the geometric model of a city's underground-, street-level and overhead-objects with a description of their functions, their surface properties, and at times even of their interior. Similar to the uses of the older 2-dimensional GIS data sets and yet older street maps, the futuristic CyberCities will serve to manage a City's resources, involve citizens in various city planning decisions, train police and the military to respond to criminal actions, particularly if they take the form of terrorism, and to support the fire departments in the case of catastrophes. Telecommunications will in this case be just one of many diverse users of urban data.

As a result there exists a wide range of data requirements not only in the isolated application to telecommunications, but also in various other municipal, military or perhaps even educational and tourist applications. The common denominator is going to be a very detailed, high resolution and sophisticated CyberCity-model of an urban environment that will satisfy even the most demanding requirements. Figures 9 through 12 illustrate this with examples that go from a city's model in the form of city blocks via individual buildings to even a building's or facility's inside, for example obtained with the software system Foto-G and the associated data collection process (Mack, 1998).

Figure 9: Representing an urban area by means of its city blocks (courtesy M. Gruber), in (a) as geometric shapes, in (b) with superimposed photographic texture.

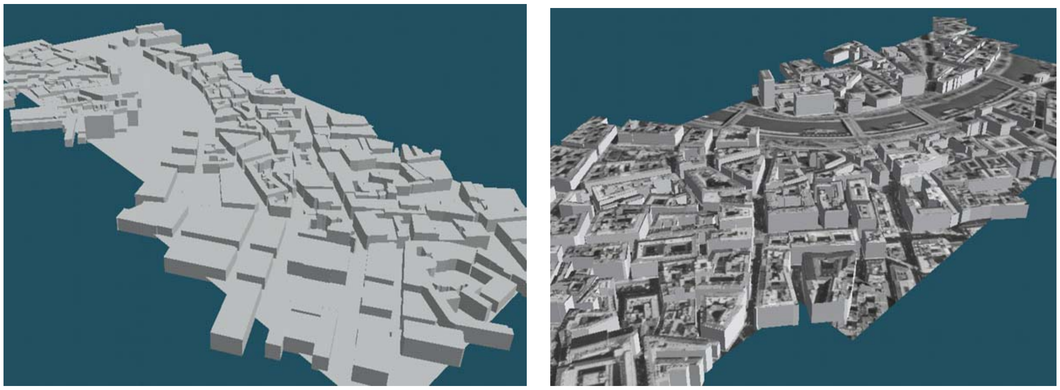
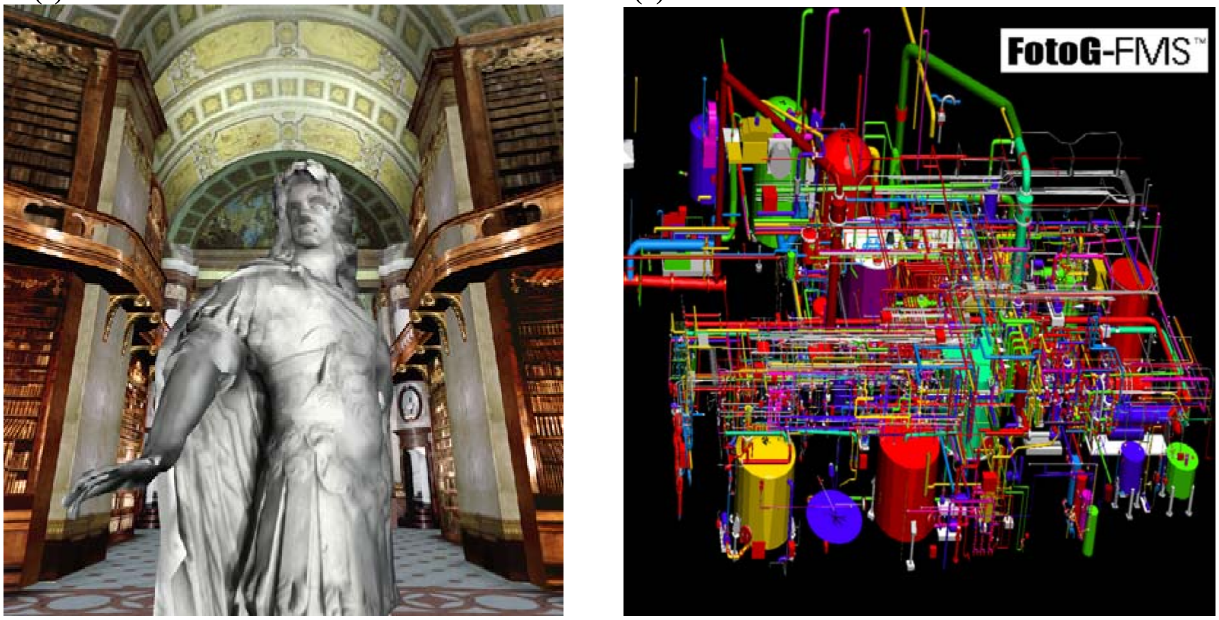


Figure 10: 3-dimensional urban model using simple geometric shapes of buildings (source: Gruber et al., 1995).

Figure 11: Refined urban model with detail on the buildings such as chimneys (by H. Holzer).

Figure 11: Modeling even the interior of buildings is of interest in historical structures as in (a), taken from a full 3-dimensional model of the interior of and of course in highly complex facilities such as that obtained by means of the software system Foto-G shown in (b), see also Mack (1998).



(a) Historic architecture

(b) Industrial structure

5. OPTICAL VERSUS RADAR IMAGES AS A DATA SOURCE

Figure 5 was an initial reference to the ability of radar imaging systems to provide accurate and useful terrain information. Buildings and other vertical objects, however, require a geometric resolution of radar images that is higher than that for a mere DEM. Figure 12 presents so-called slant range images form an airborne radar imaging system built and operated by Sandia National Laboratories. Such a radar system is capable of observing the terrain elevations directly via interferometric techniques, but the extraction of individual buildings still requires a look at the images themselves. Figure 13 presents one of the buildings in Figure 12 and illustrates that its reconstruction from the all-weather, day-and-night source material is possible with multiple and thus redundant measurements for each of the building's dimensions, and an accuracy within about ± 1 m.

The continued refinement of synthetic aperture radar sensing in terms of interferometry, geometric resolution and wide coverage feeds the expectation that modeling of urban environments may be feasible not only from optical sources, but also from high resolution radar images.

Figure 12: Synthetic Aperture Radar (SAR) images in slant range of some buildings in a small village. The SAR system resolves about 1 foot per pixel and is built and operated by Sandia National Labs. The example shows four views from right angles and from opposing sides. The reconstructed building of Figure 13 is marked in the upper left image.

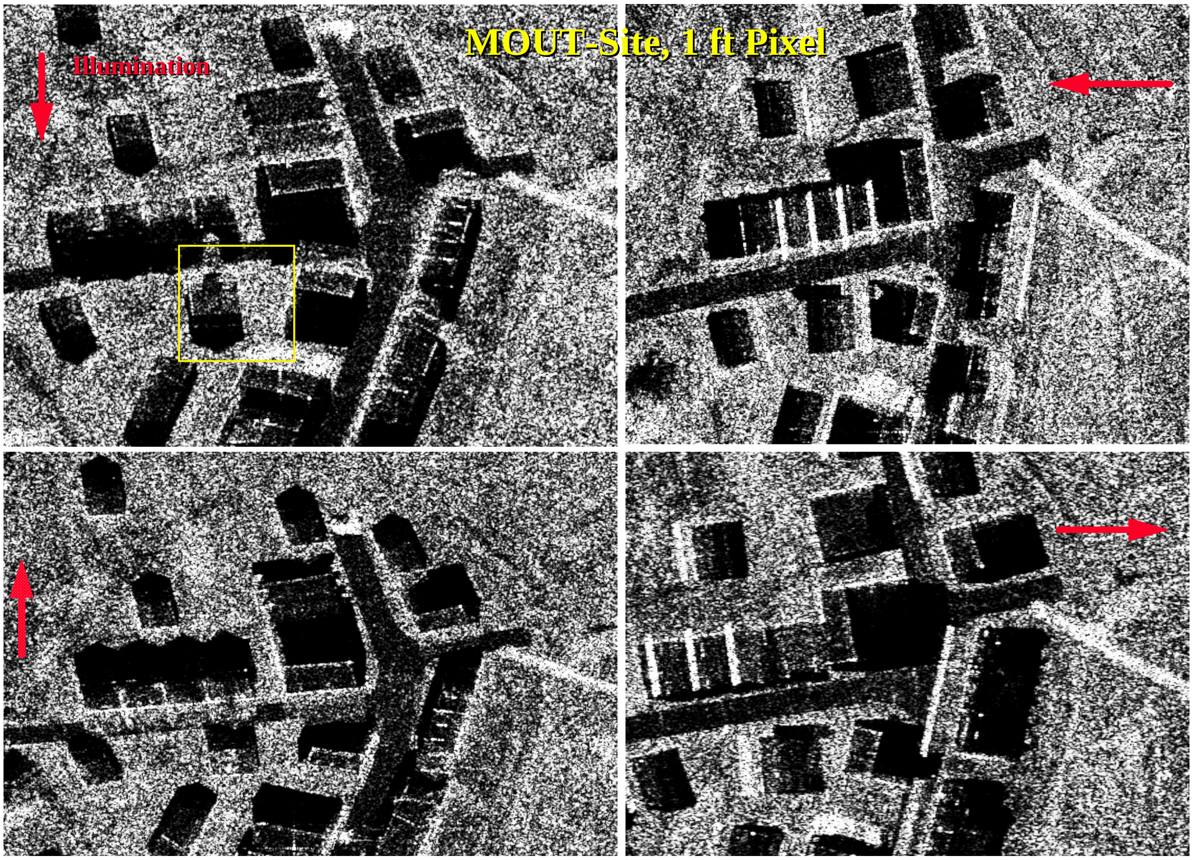
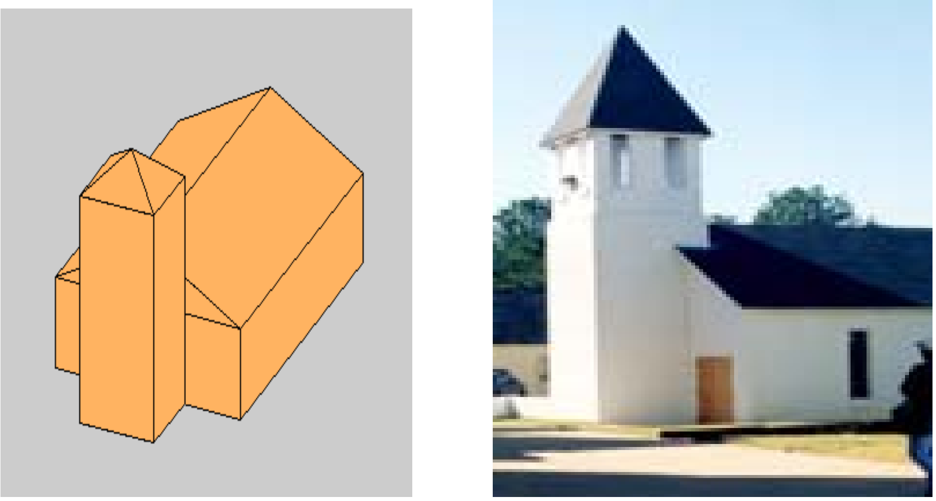


Figure 13: The reconstruction of one of the building marked in Figure 12 can be based on the interferometric elevation observations, augmented by an analysis of the image itself. The result is accurate to within ± 1 m.



(a) Axonometry derived from SAR

(b) Comparison perspective image

6. DATA OFFERINGS

A range of requirements due to varied telecommunications technologies, competitive pressures and use of different frequencies leads to a rather varied need for data types, accuracies and geometric resolutions by the telecom industry. Table 1 reviews this range of data that may be of interest.

It needs to be noted that that this is far more detailed than the traditional "urban" data sets used to plan earlier generations of cellular systems. In those cases, DEMs with postings of a mere 100 meters and a dubious accuracy were sufficient, if augmented by surface land use maps from SPOT or LANDSAT to define the regions with urban built-up terrain. Essentially this was nothing else but an application of the traditional 2-dimensional GIS. We now see a refinement with a transition to 3-dimensional objects, going from the "old" 100 m requirement to a 1 m resolution at a ± 1 m accuracy.

Table 1: Terrain data for advanced Telecommunications planning and management.

Raster Data
- Digital surface models of the reflective surfaces as seen from above
- Bald Earth digital elevation models, with vertical objects removed
- Vertical object layer

Vector Data
- Polygons describing each individual building
- Polygons describing groups of buildings, such as city blocks
- Models of high buildings, e.g. of all buildings with more than 2 stories
- Trees and other obstacles needed for lines-of sight analyses

Attribute Data
    Reflective properties of surfaces
    Addresses

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7. CONCLUSIONS

We have presented the example of a data processing chain to build 3-dimensional urban data bases with buildings and other vertical objects using non-traditional photogrammetric procedures. The current application of such data is for the planning of telecommunications networks. Depending on their technology, data may be needed at various resolutions and accuracies. Data costs and timely availability are major concerns of that industry, so that a high degree of automation in the extraction of DEMs and building data is of great interest.

While telecommunications seems to have a pioneering role in the use of 3-dimensional urban data, there is a growing general interest in a transition from the traditional 2-dimensional GIS to the idea of a CyberCity with its ability to immerse a user in a photo-realistic computer model of an existing city. Obvious applications are in various city planning functions, training of police, military and fire department personnel, tourism and others. A simple question about the intervisibility of any 2 points in a city cannot be answered by a 2-dimensional GIS, yet it is a task that is naturally addressed by an urban telecommunications data base.

We provide a glimpse at the fact that optical imagery is not necessarily the only imaging source for urban models, and that SAR-imges may also be able to provide the needed detail and accuracy of urban data.

The 1 m resolution, ± 1 m accuracy requirements of many telecommunications projects may not satisfy some of the more demanding municipal applications. One oftentimes has a need in those applications for roof lines to be defined to within ± 0.2 m, particularly when property ownership, land use planning or engineering issues are at stake. We expect that such diversity of demands will ultimately lead to sophisticated, detailed CyberCity-type 3-dimensional urban Geographic Information Systems.

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