

## THE CHALLENGES OF 3-D MODELING IN A DENSE URBAN ENVIRONMENT

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### ABSTRACT

In its traditional form, photogrammetry has developed a rich suite of procedures for measurement and mapping of natural topographic forms, including low-relief areas as well as mountainous regions. The design and operation of aerial cameras, including choices of lens focal lengths, film formats, and overlaps in both endlap and sidelap directions, are based on the premise that the photogrammetric measurement process will take place within stereo pairs, whose perspective model will permit the viewing or analytic resection of all points on the ground. Even where steep cliffs occur, the cases where a part of the model is obscured (not visible in both members of the stereo pair) tend to be the exception rather than the rule.

Recently, a great deal of attention has been directed toward the accurate representation of the „urban landscape“, in which all buildings - as well as the streets between - are measured through photogrammetric procedures. The many vertical surfaces of the faces of buildings represent total discontinuities in slope; and the amount of model area being blocked from view creates a significant percentage of the project having less than stereo coverage. This paper describes some of the requirements to be met in three-dimensional modeling of urban projects, as well as discussing some of the changes which have to be implemented in photogrammetric procedures in order to fulfill the expectations of the data users.

### 1 CHARACTERIZATION OF THE URBAN MAPPING PROBLEM

In the past, most of the mapping of urban areas has been as an extension of national mapping programs, with the possible exception that a larger scale might be used in order to contain the symbolic representation of dense proximity of cultural features. While topographic maps contain a third (vertical) dimension through overprints of contours and spot elevations, the vertical is usually confined to a description of elevation at ground level, and does not attempt to display heights of objects built above ground (unless their height would represent a hazard to aviation.). In many printed maps of cities, even the contours of ground level are omitted because of the degree of confusion caused by overprinting the complex symbology. For large-scale maps (usually having scales larger than 1:25,000), the presence of a building may be indicated by a polygon shape of its base, or „footprint“ within the map planimetry.

When aerial photography is flown for mapping purposes, most projects make use of 150-mm focal length lenses imaged on 230 mm film formats, such that 60% endlap generates a base-to-height (B/H) ratio of approximately 0.6. If the desired scale of the map product is 1:2,000, then it is likely that an image scale would be specified at 1:10,000 or larger, corresponding to flying height of about 1500 metres AGL. If we postulate the traditional 60% endlap criterion, then photo centers would be 920 metres apart. For any point more than 300 metres off the nadir, a building of 100 metres height would completely obscure the view of a street 20 metres in width on its far side. One may alleviate the problems of blockage by increasing the endlap or by using a longer focal length lens, both of which reduce the B/H ratio and, by implication, reduce the

accuracy to which vertical coordinates can be measured. Increase of endlap or focal length also imply a smaller model area, with its attendant increase in the map production costs per unit area.

### 2 URBAN DATA

Most of the projects which require precise 3-dimensional data over cities are not directed toward traditional representation as printed maps. Instead, these projects fall within the category of geographical information systems (GIS) where data are stored in a variety of geographically-keyed layers, and these layers may be extracted either individually or in combination as part of spatial analysis or modeling applications. In such applications, the buildings and the spaces between them take an active part in physical processes; and in turn, need to be accurately defined in order to understand and predict phenomena involving health, safety, and various elements of commercial enterprise.

#### 2.1 Micro-Climatology of Urban „Canyons“

There is a new field for concern in the behavior of (otherwise) natural patterns of winds, rains and temperatures when they interact with the shapes found in central areas of cities. Laminar flow of winds may be interrupted with abrupt boundaries, creating eddy currents and high-velocity vortices. Direct flow may become channeled between tall buildings, forming a wind tunnel having high-speed flow across building surfaces with attendant drops in pressure. During hurricane conditions, these locally-increased velocities have generated explosive „glass-falls“ into the streets below from buildings whose specifications should have withstood the storm's wind speed.

## **2.2 Resonance and Channeling of Acoustic Levels and Air Pollutants**

In addition to the channeling of winds and weather elements, the primarily flat-sided walls of urban canyons have the characteristics of containing and holding emissions of sound and pollutants which are harmful to humans as well as other plant and animal life. „Sound pollution“ becomes a problem primarily through resonance, wherein multiple reflections build and intensify sounds prior to their attenuation or dispersion. Airborne pollution, frequently generated by vehicles at street level, remains trapped within some pockets of incomplete circulation, creating repetitive health hazards to those working or living in the area.

## **2.3 Blockage, Reflection and Diffraction of Telecommunication Signals**

As wireless communication has become more important for today's mobile society, dense urban centers have become filled with users requiring more channels, clearer signals, and continuous coverage. Additionally, the development of business applications needing wide-band communication have grown at explosive rates during the current decade. The „old“ cellular telephone technology made use of antennas placed high to radiate for maximum distance of coverage; but as these cells became too saturated to support usage, the industry had to move toward „micro-cells“ placed at or below roofline in order to reduce cell coverage area and be able to make use of the same broadcast frequencies at some nearby location without generating signal interference. Each surface of a building could serve as a radio signal reflector, and each building corner or ridgeline of a roof could diffract the cellular transmissions.

For modeling and predicting such signals, the communication operating companies began to make use of network prediction software in which a full, 3-dimensional representation of the buildings was included. As additional, higher frequency bands of the radio spectrum have been released for communication, the requirements for accurate building locations, shapes, and heights have increased.

## **2.4. Accuracy Requirements For Support Of 3-D Models**

The modeling applications listed above include a range of requirements for data, including different levels of spatial density, different accuracy levels, and a considerable range of data formats. What appears to be a common thread is that the models for radio communication are usually the most stringent - particularly at higher frequencies - and tend to specify both horizontal and vertical accuracies within the range of 1 metre. In a few cases, there are cautionary warnings which must be issued. For example, there are some software models for radio signal propagation which use „ray-tracing“ algorithms, and which may incorporate multiple reflections of signals off building surfaces. In such cases, there are implicit assumptions about the angles between planar faces which may be more stringent than the statements made about requirements for absolute positional accuracy of the buildings.

## **3 REQUIRED: A NEW PHOTOGRAMMETRIC PARADIGM**

Following several years of experience in generating 3-dimensional data sets to satisfy a number of urban modeling applications, it has become clear that the old „rules“ for photogrammetric data acquisition and production have to undergo considerable change. Some examples are considered below.

### **3.1 Less Dependence on the Stereo Pair as the Basic Photogrammetric Model**

One of the primary areas of change, both in planning and in performance of urban photogrammetry projects, is a departure from the stereo pair as the primary element in extracting both planimetry and height information. As noted previously in this paper, the abundance of vertical surfaces among tall buildings creates a high degree of blockage of view from any single point of perspective, such that off-nadir areas are imperfectly measured. This limitation is only removed if the measurement procedures invoke multiple model pairs, or are based on photogrammetric procedures including more than two frames at a time. This has long been the case in bundle adjustments in analytical triangulation, where multi-ray intersections have been used, but in particular must include the diversity in azimuths among camera perspective points to permit filling the zones of blockage.

### **3.2 Modification of Aerial Photo Acquisition Parameters**

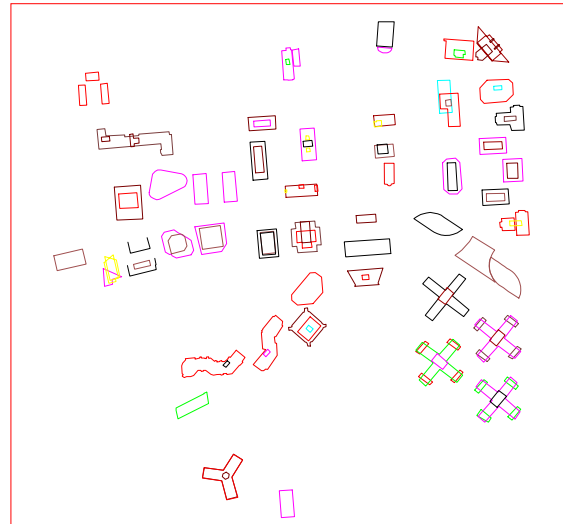
In order to achieve the full range of perspectives required to show all sides of tall buildings in a dense urban setting, aerial photo acquisition parameters need to be modified away from the „standard“ 60% endlap, 30% sidelap which has worked well in general topographic mapping. One obvious ploy is to change sidelap to exceed 50% in order to have all areas covered by models from adjacent flight lines. Even this does not insure that one can observe features at street level near the center of sidelap. However, by increasing endlap to some level above 67%, there is a 6-way coverage provided, such that each point is (theoretically) viewed from each of 6 perspectives. This acquisition design, usually specified as 70% endlap, 55% sidelap, has proved to be effective in providing complete coverage for building faces in cities of high building density.

### **3.3 Development of Interactive Tools for Point and Surface Measurement**

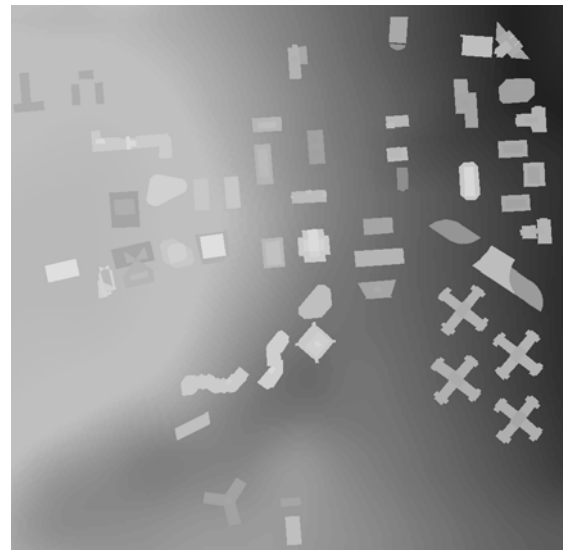
Following the conceptual leap required to move away from conventional photo acquisition design and use of stereo pairs as measurement models, one is required to move into a new arena of measurement concepts and practices. The authors have performed a number of joint projects in such „tool design“ activity, and have achieved results which reflect the value of the paradigm shift (Figure 1). These development activities are noted below.

- While there is considerable potential for high degrees of computer automation in the measurement process, the dissimilarities in lighting and perspective views of images of buildings have shown that operator-machine interaction is still highly effective.
- Departure from the traditional construction of stereo pairs (e.g. epipolar resampling of images) has brought about simplifications in pre-measurement processing.
- Incorporation of measurements (resections) from multiple images has more than restored accuracy to measurements which had been reduced by decreases in B/H ratios.
- Procedures in high-precision measurement of building shapes can be taught and learned in periods of time much less than equivalent training of stereo operators.

A variety of urban studies involving the use of 3-dimensional coordinates developed with new and/or modified photogrammetric procedures will be considered.



A.



B.

Figure 1A. A plan view of building roofs.

Figure 1B. Gray levels indicate rooftop elevations (dark=low; light=high). A DEM of the bare earth underlies the buildings.