

# A SURVEY OF 3-D URBAN MAPPING AND VISUALIZATION CAPABILITIES FROM AN ARMY PERSPECTIVE

Tom Witte

U.S. Army Topographic Engineering Center, Engineer Research and Development Center, Alexandria, VA

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## **ABSTRACT:**

There has been a fundamental change in the nature of security and armed conflict. Traditionally avoided if possible, urban areas have become likely battlegrounds. Since many military operations will take place in cities now and in the future, the U.S. military must be prepared to engage in operations in urban areas. A major key to success in such missions will be the ability to conduct realistic training. It follows that there is a need to represent real-world urban areas accurately and effectively, to support U.S. military mission planning and operations. This implies a need for urban mapping and visualization capabilities. However, the complex terrain of urban areas poses numerous challenges - dense populations, the presence of non-combatants, difficulties in moving undetected through such areas, restrictive maneuver space, difficulties in locating targets, variations in the composition of obstacles, the dangers of snipers, compressed decision times, short ranges of visibility, etc. Naturally, the U.S. Army seeks the best possible situational awareness to support each mission, and this is especially critical for missions that entail urban warfare. Unfortunately, there is a distinct lack of suitable urban information for much of the world. Some urban areas have been well modeled, but there is little or no geospecific information for other areas. This paper seeks to address what is currently possible with regard to urban mapping and visualization, given prevailing constraints with regard to sensors, data and tools. The paper will consider a range of user requirements and will identify solutions for a range of scenarios, from worst case to ideal case. The paper will attempt to pair various kinds of data with appropriate tools, and will also describe what kinds of data and tools are needed given a set of requirements. The paper will discuss methods and applications, and will also include data characterizations and brief product descriptions. These product descriptions will include software tools to extract 3-D urban features from sensor data, software tools to visualize existing 3-D urban data holdings, software tools for interactive 3-D navigation of urban data, and software tools that support analyses of 3-D urban data.

## **INTRODUCTION**

It is likely that many or most future U.S. military operations will have an urban component; cities have become the primary sanctuaries for many contemporary and emerging threats. However, the urban setting tends to be a complex and difficult environment in which to operate, and urban combat remains a special challenge. Urban terrain elements such as the physical layout of built-up areas and the structural characteristics of buildings impact the tactical options available to commanders. Thus, the Army has identified the capability to visualize real-world urban terrain in 3-D as a critical need.

## **EXISTING DATA**

Suppose a crisis arises, and U.S. forces must contemplate operations in an urban area, somewhere – anywhere - in the world. What kinds of data might be available to support military operations? And, given whatever data might exist for this particular urban area of interest, what can the Army do? In other words, what can one do with what one has? The quantity and quality of data available for urban areas throughout the world varies widely. It should be noted that it is the mission of the National Geospatial-Intelligence Agency (NGA) to provide timely,

relevant, and accurate geospatial intelligence in support of national security objectives. However, this paper focuses on specific Army requirements and applications.

## **Urban Tactical Planner**

The Army has a standard urban data product today. This is the Urban Tactical Planner (UTP), a product of the Operations Division of the U.S. Army Topographic Engineering Center (TEC). UTP development began in 1996, in response to the Army's growing need for up-to-date geospatial information describing urban environments. The UTP is based on ESRI ArcGIS software, and can exploit data inputs such as commercial imagery, NGA Digital Terrain Elevation Data (DTED), intelligence sources, etc. TEC can produce a UTP in about six weeks, depending on the size of the urban area of interest.

In a UTP, the urban environment is displayed as an aggregate of features that might affect military operations, such as building form and function (represented as polygons of similar building types), building height, vertical obstructions, terrain features, bridges, lines of communication, key cultural features, landmarks, etc. These features are shown as themes or layers that can be displayed or not, as decided by the user. Attribute tables that provide additional information

are linked to these layers. In addition, hot-links provide the user with more information (if available), such as ground photos, architectural drawings or site plans. These themes or layers are displayed atop a map or image base at the user's discretion.

Users can apply UTP data to their specific needs. For example, an Army aviator can choose to display only those features that affect navigation, such as landmarks and suitable landing areas. Planners for ground operations can elect to display urban areas that will likely be occupied by noncombatants, show approach routes, and display key urban terrain, such as a minaret that could serve as a sniper's lair.

Each urban area is presented at varying degrees of detail. A user can display an overview of the area (showing relief and major routes, for example), zoom in for a larger scale view, and ultimately reach a one square kilometer view of a selected site or sites within the area. The product can be tailored to specific customer requirements.

The UTP has undergone various enhancements, and continues to evolve. Currently, UTPs are built as ESRI Geodatabases, and use NGA's Feature Attribute Coding Catalogue (FACC) structure. The level of information provided for a given urban area is related to its priority.

Additionally, associated Skyline Software TerraExplorer files are being created and posted, to enhance the ease of use and visualization capabilities of UTP data. TerraExplorer adds capabilities for interactive 3-D viewing and virtual navigation. With TerraExplorer, building footprints are extruded based on their associated height attributes.

There are several levels of UTPs now, with varying levels of content. Level I is simply rectified imagery of the area of interest. Level II includes imagery, DTED, and a fly-through capability. Level IIIA includes built-up terrain zones (BTZs), key features and buildings of interest. Level IIIB provides vertical obstructions, open urban areas, airfields and associated text pages. Level IVA includes roads, railroads, bridges, water and ridgelines. Level IVB provides extra photos, forests and even underground systems.

Previously, UTP customers had to wait until a product was complete before they got any information about a given area. Now, users receive varying levels of information - starting with image data only - as it is produced.

UTPs are deliverable electronically and via CD-ROM. A requestor can have TEC produce the underlying data and the product itself, or TEC can provide just the data (images, digital maps, etc.) to the customer for his own analysis. Military customers can access a library of completed UTPs.

## Other Data Options

Suppose a military commitment arises in a place for which UTPs have already been generated. In this simple case, the appropriate UTPs are disseminated to the appropriate parties, and are used to support operations in the area of interest. However, if UTPs are not available or are not considered adequate, other data options must be considered.

Perhaps it should be noted that urban mapping and visualization for Army applications requires information about areas that are likely to be inaccessible prior to operations. However, high-resolution remotely sensed digital data are becoming widely available. This increase in the supply of data has helped to make 3-D visualization of cities more feasible.

In fact, there are now companies that advertise themselves as providers of 3D city models. These include CyberCity, GeoSim, EarthData, Planet 9 Studios and Vexcel. Thus, it is now possible simply to purchase an existing 3-D model of a city. Done correctly, a 3-D urban model is based on accurate building geometry (including true roof types), with real-world imagery applied as texture to the faces and roofs of buildings. There is increasing demand for this kind of photorealistic 3-D city model, for a variety of industries. In the ideal case, a detailed 3-D model would already have been created for the urban area of interest and would be available for purchase. However, there are many cities in the world, and relatively few have already been modeled in this fashion to date. Furthermore, it is highly doubtful that the U.S. Army's next urban hotspot will be available as an off-the-shelf 3-D virtual model.

It's possible that geographic information system (GIS) data will already exist for an area of interest. In this case, a software product like TerraSim TerraTools can be used to automatically create a 3-D database, using the extant geometry and attributes. Once the database has been generated, TerraSim's free 3-D viewing software called TSGFly can be used for interactive navigation of the virtual urban area.

If no 3-D model exists, then one must be created. What if high-resolution stereo imagery is available for the area of interest? Trained personnel can then use software tools like BAE Systems SOCET SET or Leica Geosystems Leica Photogrammetry Suite to perform stereo feature extraction. This process requires an operator to view urban features in stereo, digitize vector representations of them, and save them in the desired format for subsequent exploitation.

What if there is no stereo imagery, but there is high-resolution monoscopic imagery, such as from Digital Globe QuickBird or Space Imaging IKONOS satellites? In this case, GeoTango SilverEye software can be used for urban feature extraction. By exploiting a rational function model (RFM), SilverEye enables a user to extract 3-D models from a single high-resolution

commercial satellite image, without requiring a stereo pair.

Airborne LIDAR sensors directly measure terrain surfaces, including objects that rise above the ground (e.g., buildings and trees). LIDAR typically maps a relatively small area with high accuracy. Urban features tend to be easily discernible among the dense point clouds collected by LIDAR systems. The result is commonly known as a digital surface model (DSM). With LIDAR data, one can extrude buildings by using the height values of footprints that comprise building polygons, or preserve the original DSM to capture more complexities of shape.

If LIDAR data have been collected for the area of interest, there are some processing options. For example, the Johns Hopkins University Applied Physics Laboratory (JHUAPL) has designed QT Viewer software to import, display and manipulate 3-D LIDAR data.

However, due to the vulnerability of current platforms, it is unlikely that LIDAR data will be available for a given contingency area for planning prior to military operations. (However, it should be noted that research is ongoing to address platform issues as related to the use of LIDAR for military applications.) After operations, though, LIDAR can be useful for reconstruction efforts. For example, Mosaic Mapping Systems collected LIDAR data in Afghanistan to support rebuilding the road between Kandahar and Herat.

If hyperspectral data are available, it is possible to determine building material types. This determination can be accomplished with the help of a software tool such as Research Systems ENVI or even TEC's own Hypercube program. However, it should be noted that this kind of data is seldom readily available today.

What if blueprints or similar data are available for a building or buildings of interest? A tool like @Last Software SketchUp can be used to create 3D models from this kind of information. The software can also work in conjunction with ArcGIS to provide geospatial context for modeled features. ArcGIS 3D Analyst can import SketchUp models, for further analysis.

Suppose 3-D data products are available, but are not in the desired format? A software tool like Okino NuGraf can help. NuGraf supports 3-D file translations, rendering, material editing, scene optimization and interactive viewing. It comes with converters and optimization tools for a wide range of graphics file formats. Users can convert, view and render 3-D models and scenes. For example, NuGraf can convert from the OpenFlight format to 3D Studio (3DS) format. Guthrie CAD2Shape is a product that converts AutoCAD DWG and DXF files to ESRI SHP files. Guthrie Arcv2CAD unsurprisingly converts ESRI SHP files to AutoCAD DXF and DWG formats.

Security classification is also a significant issue. One of the main benefits of commercial images such as obtained from IKONOS, QuickBird and OrbView-3 is that they are unclassified, and can be shared with U.S. Army soldiers and coalition partners without restriction.

## SOFTWARE OPTIONS

### Application Requirements

Again, suppose a crisis arises, and U.S. forces must contemplate operations in an urban area somewhere in the world. Another approach considers the intended application first. In other words, what tools are needed to meet the Army's requirements for this particular urban mission?

People can have very different requirements. For some, speed is the top priority. These people might prefer a rapid or highly automated process of generating 3-D urban environments. However, automated processes tend to simplify or generalize features.

Simply draping imagery over a digital elevation model can be accomplished very rapidly, and can provide some level of geographic familiarity for mission planners. However, buildings, trees and other objects with height above the ground will not stand out from the terrain surface; they will simply appear as smears on the local topography.

Nevertheless, some customers might be satisfied with a simple fly-through that uses imagery draped over elevation data. This can be done with Leica's IMAGINE VirtualGIS product, using NGA DTED and either NGA imagery or a commercial source such as Space Imaging or DigitalGlobe. It can also easily be accomplished with Skyline Software TerraExplorer, ESRI ArcGlobe, and other products.

Perhaps crude representations of urban structures will suffice. Extruding building footprints and assigning flat roofs can be automated, and this provides somewhat more urban detail than a simple image drape. Without texturing, however, buildings generated in this manner will appear as cartoonish, colored cubes atop the landscape.

If more accurate 3-D buildings are required, they must be extracted first. This can be accomplished using stereo imagery and softcopy stereophotogrammetric tools such as BAE Systems SOCET SET or Leica Photogrammetry Suite. However, this can add significantly to production time.

For some users, the top priority is visual accuracy. This tends to require a process that includes manual intervention to model complex features as realistically as possible. For example, it might be necessary to faithfully portray complex building shapes and roof types. Realism also requires that a building model be textured with

imagery of the building itself – geospecific texture, as opposed to geotypical texture.

What if accurate representations of building facades are required? This means that oblique images and/or terrestrial LIDAR data will be needed. Oblique images can provide the geospecific texture data necessary to convey the true appearance of a real-world building. Terrestrial LIDAR data can provide the geometry needed to accurately model a real-world building.

A tool like InnovMetric PolyWorks can be used to process terrestrial LIDAR data. Users can view data in 3-D; make measurements; analyze points to detect outliers; merge data from different scans; integrate data with floor plans, engineering drawings and survey data; generate contours, profiles and cross sections; calculate volumes; and generate CAD models. The software supports a user-definable feature code library that can assist in identifying features.

Some users might require knowledge of specific building interiors, and even the underground infrastructure. A product like TerraTools can visualize this kind of information; of course, the daunting problem is obtaining the original data.

Another consideration is whether the intended user requires interactive viewing of the 3-D urban data, or a pre-recorded fly-through or walk-through will suffice. Army users tend to prefer to view a 3-D scene from any viewpoint and any possible route, but there are, of course, trade-offs between the degree of realistic details and the level of acceptable computer performance.

What if the user not only wants to view an area in 3-D, but also wishes to be able to click on objects within the scene to obtain more information? This requires a link from the 3-D visualization to a GIS database. Software by ITSpatial and TerraSim can provide this linkage.

It could be that the requirement is to support the Army's One Semi-Automated Forces (OneSAF) simulation program. The OneSAF Testbed Baseline (OTB) uses an optimized run-time format called CTDB (Compact Terrain Database). TerraSim TerraTools and TERREX Terra Vista are two software products that support the CTDB format.

OneSAF is intended to support special forces, and military operations in urban terrain (MOUT). This support includes capabilities to simulate military operations inside buildings. Thus, building interiors must be modeled. In OneSAF, a building can be represented as a simple box with texture maps on the exterior to provide the visual appearance of windows, doors and architectural details. However, a building can also be represented as a multi-elevation surface (MES) structure in which the exterior (doors and windows) and interior (walls, ceilings, floors and doors) are modeled in a

specific format that allows simulated movement throughout.

SAIC has developed software to model buildings in the required format to produce a CTDB database. The company has written an AutoCAD plug-in to produce MES files from DXF data, and a MultiGen Creator plug-in to produce MES files from OpenFlight data.

The newer OneSAF Objective System (OOS) uses the Objective Terrain Formation (OTF). The Army is currently working with TERREX and TerraSim to ensure that their commercial tools can output this new format

### **Software Products**

For many years, TEC has maintained a document called "The Survey of Terrain Visualization Software." This report contains information on hundreds of software products that support some form of 3D topographic representation. It includes many types of products: real-time visual simulation software, GIS programs with capabilities for 3-D rendering and analysis, multi-disciplinary scientific visualization tools, modeling/animation packages, terrain modeling tools, tools for deriving 3-D models from multi-angle photography, and even some unusual alternatives such as holographic products and products that generate solid terrain models. The information has generally been obtained from open sources such as vendor literature and trade journal reviews.

If a similar report were to cover only those products that are designed to visualize urban areas in 3-D, it would be a much smaller subset. Nevertheless, there are numerous products available that support 3-D urban mapping and visualization. These products vary in many ways, including cost, capabilities and applications. A few representative products have been listed below. They are mentioned only as examples, and it is not intended that they represent every possibility. Omission of a particular product does not imply that it lacks relevant capabilities.

For example, with ESRI ArcGIS 3D Analyst, a user can import a 2D building data layer (including attributes such as height, footprint, top print and address), extrude the building footprints according to height attributes, generate and add 3-D building top prints, add a thematic map layer, set the results onto a bald-earth digital terrain model, calculate the elevations of the building tops, correlate addresses with a database of structures such as cell towers, place bitmap images of towers at the appropriate addresses, and calculate view sheds for each tower. Users can also build true 3-D models that are not just extrusions of 2-D polygons. These 3-D objects can be stored in an ESRI Geodatabase and be rendered and queried within ESRI ArcScene.

Planet Nine Studios eScene software uses game technology to provide a 3-D city interface, coupled with tools for visualization and analysis. There is a special MOUT version of this product.

Harris RealSite provides capabilities for generating and visualizing 3-D urban models. The software uses imagery from multiple sources and sensors. Intended applications include mission planning and rehearsal, line-of-sight analysis, etc.

A companion Harris product called InReality provides capabilities to navigate virtual scenes and conduct various analyses. Users can place themselves within 3-D scenes, display their fields of view, add and remove waypoints, etc. There are three viewing modes – flight, mensuration, and ranging. Ranging mode enables users to calculate line-of-sight ranges, e.g., from a user's position to a window where a sniper might be located.

ITSpatial InterSCOPE links 3-D geospatial models with GIS data. The software provides an integrated, real-time visual interface for analysis, mining, linking and visualization of geographic and related data. The functionality exceeds that of 3-D fly-throughs alone, by enabling interactive query and analysis of 3-D feature attributes.

Kinetic Solutions SCOUT is designed to support tactical response teams during crises that occur within critical infrastructure (schools, power plants, courthouses, embassies, sports arenas, airports, etc.). It is designed to provide crisis managers with data regarding the interior environments of buildings and other structures. A user can remotely access images and descriptive data about a facility, and can roam virtually from room to room and from floor to floor to track response teams. SCOUT integrates aerial images, panoramic images, floor plans, CAD drawings, etc.

Precision Lightworks Nverse Photo is an image-based tool for creating 3-D models of urban areas. The product does not require stereo imagery or special hardware, and can export models in OpenFlight and SHP file formats.

MetaCreations Canoma is another tool with which users can create 3-D models of small urban areas from scanned or digital photographs. The software is designed primarily to model man-made scene elements, such as architectural interiors and exteriors.

MultiGen-Paradigm's SiteBuilder 3D is a plug-in to ESRI ArcGIS software. This product allows users to visualize GIS data in 3-D, and conduct virtual 3-D fly-throughs while tracking their 2-D positions in ArcGIS. SiteBuilder 3D can also export scenes in OpenFlight format.

TerraSim TerraTools is a standalone product designed to facilitate the rapid construction of geospecific databases using a variety of cartographic sources, imagery, and CAD and GIS data. The software supports the

parametric generation of complex urban geometry, with a relatively high level of automation. Users can export databases in a variety of formats, including those that support military modeling and simulation (M&S).

The BAE Systems SOCET SET Plug-in for TerraTools provides an interface for exporting SOCET SET projects (imagery, cartographic feature data, and image-textured models) to TerraTools. The plug-in creates a TerraTools project flow graph for automatic database visualization. Imagery associated with a SOCET SET project is imported into TerraTools and can be used for textured terrain and backgrounds in the TerraTools feature viewer. The plug-in automatically converts SOCET SET features to the TerraTools feature representation, preserving all attribution and enabling customization.

TERREX Terra Vista is another software product with the ability to generate 3-D buildings from vector source data without any external modeling required. Buildings are generated automatically, based on vector data attribution and user-controlled parameters

Object Raku Technology SEXTANT Virtual Warfighting Tool (VWT) is software designed to support mission planning and rehearsal of operations involving urban terrain. The product has both 2D and 3D display modes.

Advanced Interactive Systems SVS provides an independent viewpoint into virtual environments. Users can view simulations from any location within the virtual space, in a variety of modes. This product supports the OpenFlight format, and can, for example, be used for 3-D visualization of urban databases built with TerraTools.

TerraSolid TerraScan is a specialized application designed for processing large point cloud data sets, and is suitable for both terrestrial and airborne LIDAR applications. This product is a plug-in to Bentley MicroStation.

Marconi Wireless deciBel Planner is a radio frequency (RF) propagation modeling and network analysis tool. EDX Engineering SIGNAL is another planning tool for wireless communications systems. SAIC Urbana is a computational electromagnetic tool for simulating wireless propagation and near-field radar sensors in complex environments such as urban areas.

## Trends

Some welcome trends have emerged with regard to 3-D urban mapping and visualization, and the lines between previously separate domains are becoming less distinct. This is happening between the worlds of CAD and GIS, and GIS and M&S.

There is a trend in which CAD and GIS programs have been integrating some of each other's capabilities. CAD vendors like Autodesk and Bentley are incorporating GIS functions into their products, and GIS vendors are incorporating CAD-like drawing and editing tools. For example, ESRI ArcGIS 9.0 reads file formats from Autodesk AutoCAD, Bentley MicroStation, Graphisoft ArchiCAD and @Last SketchUp; and includes a bi-directional CAD-GIS translator.

There is another trend in which software for 3-D viewing is being decoupled from software for generating 3-D databases. This viewing software tends to be relatively inexpensive, and in some cases is provided at no cost. For example, TSGFly, a viewer for 3-D databases generated with TerraTools, is free. TerraExplorer, software for viewing databases generated with Skyline Software TerraBuilder, is free. SEXTANT Virtual Visualization Tool (VV2) is free software for viewing 3-D scenes and associated 2-D images created with Object Raku Technology SEXTANT. IM/View is free software for viewing point cloud data processed with PolyWorks software.

### **CURRENT RESEARCH**

TEC's Research Division is currently engaged in a project called Urban Mapping. Results from this effort will support tactical mapping and 3-D visualization of cities, and will facilitate the construction of M&S databases used to train soldiers for urban combat. This project should positively impact military products and systems, including OneSAF and TEC's own UTP.

Specifically, the Urban Mapping project focuses on innovative technologies and methods to generate accurate, realistic 3-D building models from high-resolution data sources such as LIDAR, and to identify building material types from hyperspectral data. These efforts will result in improved and validated software to extract urban features from LIDAR data, and documented processes for obtaining building material types from large-scale spectral data. Ultimately, the Army will gain capabilities to generate realistic 3-D virtual building models along with associated material types.

TEC's LIDAR research focuses on enhancing software originally developed at the University of Southern California (USC) and integrating it with ESRI ArcGIS software to promote ease of use and accessibility. This software enables semi-automated generation of highly realistic 3-D building models – including complex roof geometry - from LIDAR data.

TEC's hyperspectral research entails the development of a spectral library, the evaluation of classification algorithms to derive building material types, and a report that will document the processes involved in determining building material types from hyperspectral data.

TEC is also a member of the Advanced LIDAR Exploitation System (ALES) consortium, which aims to

improve the state of the art in LIDAR-based feature extraction. ALES entails the enhancement of Visual Learning Systems Feature Analyst software, to enable it to derive bare-Earth digital elevation models and generate vector files to represent buildings and trees. As a participant in the ALES project, TEC is engaged in testing and evaluating this software.

TEC collaborates with Joint Precision Strike Demonstration (JPSD) programs that deal with LIDAR data collection, processing and exploitation. These include the Urban Recon Advanced Concepts Technology Demonstration (ACTD) and the Tactical LIDAR program. TEC also worked closely with JPSD on the now-completed Rapid Terrain Visualization (RTV) ACTD, Urban Recon's predecessor.

### **CONCLUSIONS**

The U.S. Army has demonstrated increased interest in urban issues, as is evident by the recent proliferation of related Army-sponsored meetings and conferences. The Army is definitely cognizant of problems related to 3-D urban mapping and visualization, and is working diligently toward improving its capabilities in these areas. The state of the art is progressing. Data availability is still an issue, but it is improving with the increasing availability of commercial satellite imagery and the growing number of companies offering 3D geospatial products. Now the challenge is to realize the potential of the data, to develop software tools that can truly exploit 3-D geospatial information, especially for urban areas. Data collection has improved; processing has improved; production has improved; now it is time for analysis to improve.

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### **Caveat**

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