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Honolulu, Hawaii Building Footprint Geo-Database Project: 3D Urban Visualization Paper# 1693

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ABSTRACT

The Building Footprint Geo-Database Project (Project) was undertaken by the City and County of Honolulu (City), Department of Planning and Permitting to further enhance the City's existing Geographical Information System (GIS). The City contracted USI-Hawaii Inc. to implement data acquisition and Geo-Database development. The Project examined acquisition methods and building data sources, evaluated building geometry extraction software, planned implementation and data acquisition for the island of Oahu, designed a Building Footprint Geo-Database, and implemented an initial Project phase. This paper summarizes methods used to implement the Project which delivered user data requirements and system assessment reports, system design documents, work plans, aerial photography, A*rcGIS* control point maps, ESRI Geo-Databases, *Nverse Photo* project files, *ArcScene* project files, and fly-thru animations. *ArcGIS 9* enhanced functionality will greatly improve the users experience with 3D spatial information and enhancement. All of these enhancements in technologies and data acquisition will further support necessary City services for land use planning, tax assessment, construction permitting, utility management, homeland security, and other major programs.

1 FORWARD

Building footprints have typically been created and maintained as a 2D polygon with or without building height data. With improvements in GIS 3D viewing, i.e., *ArcScene*, users have been able to extrude these polygons to create simple models. These simple models fall short of characterizing the building architecture. Converting 2D as-built drawings and designs of 3D buildings is very costly. Likewise, CAD files would be costly to convert as these are more often used in 2D rather than 3D to create building plans. Acquisition of 3D CAD files from architectural firms would also be cost prohibitive.

Aerial photography has been used as a primary source of building footprints while commercial satellite imagery has only recently advanced enough to provide the required detail to begin to compete. Aerial photography was used for this Project as image resolutions need to be at least 1 foot per pixel. High resolution images provide the ability to precisely measure elevations and produce the best building models. Low resolution images may only be able to pick up a few pixels of elevation displacement from one image to the next and results in poor building models with roughly the same amount of effort.

The exciting development in this Project is software improvements that allow the capturing and visualization of detailed building shapes, roof morphology, and realistic texturing from aerial photography. Similar types of 3D software packages use stereo imaging which is an off-shoot of the days when photogrammetrist would use zoom transfer scopes and other stereo viewing equipment. Typical stereo viewing software requires users to wear glasses and use special computer pointing devices to navigate through images while capturing 3D data.

Nverse Photo allows users to work comfortably in a 2D environment and capture 3D buildings, surfaces, and other structures. Modeling urban environments has never been easier. We are excited about what we have accomplished in Honolulu and we hope you will benefit from our experience.

2 INTRODUCTION

The Building Footprint Geo-Database Project (Project) was undertaken by the City and County of Honolulu (City), Department of Planning and Permitting to further enhance the City's existing Geographical Information System (GIS). The City contracted USI-Hawaii Inc. to implement data acquisition and Geo-Database development. The Project examined acquisition methods and building data sources, evaluated building geometry extraction software, planned implementation and data acquisition for the island of Oahu, designed a Building Footprint Geo-Database, and implemented an initial Project phase.

This paper summarizes methods used to implement the Project which delivered user data requirements and system assessment reports, system design documents, work plans, aerial photography, *ArcGIS* control point maps, ESRI Geo-Databases, *Nverse Photo* project files, *ArcScene* project files, and fly-thru animations. *ArcGIS 9* enhanced functionality will greatly improve the users experience with 3D spatial information. All of these enhancements in technologies and data acquisition will further support necessary City services for land use planning, tax assessment, construction permitting, utility management, homeland security, and other major programs.

These following sections cover the 1) Project Work Plan and Implementation, 2) Modeling Methods for Buildings, 3) Visualization, and 4) Building Footprint Geo-Database Applications. The Project Work Plan and Implementation section discusses the project preparation, implementation software, and acquisition of aerial photography, digital image requirements, SDTS DEM acquisition, ground control points and image registration. Modeling Methods outline the simple geometric primitives used to construct a building model. Visualization discusses building and ground textures, Ortho-Rectification, the setup of images, models, and cameras used to prepare a fly-thru animation. Building Footprint Geo-Database Applications focuses on improving the user experience by leveraging *ArcGIS 9* to process 3D spatial information.

3 PROJECT WORK PLAN AND IMPLEMENTATION

3.1 Project Preparation and Deliverables

The City implemented, to some degree, all of the initial GIS planning steps, e.g., strategic business plan review, planning proposal, technology seminars, user needs, and requirements analysis. This Project determined the City GIS system scope, decided on a preliminary system design, provided a work plan, and 4) implement the work plan.

Three preparatory steps were taken prior to the Project implementation. This delivered the following three Building Footprint Project documents:

1. Source Data Analysis & Design Report
2. Geo-Database Pilot Study – Software Evaluation
3. Work Plan & Pricing Proposal

Figure 3-1: GIS Planning & System Life Cycle

With the Project planning documents now in place, USI-Hawaii proceeded with creating the following major contract deliverables:

4. Animations, 640 x 480 30 fps, 1 minute (4 -preliminary & finals)
5. Nverse Photo Project Files
6. Control Point Map Book (for locating ground stations)
7. Geo-Database System Design Report
8. 4 - Building Footprint Geo-Databases
9. 4 - ArcScene Project Files & GIS layers (clipped DEM, Background, Ortho-Photo)

Figure 3-2: ArcScene Models and Deliverables

The Source Data Analysis & Design Report established the system scope for the building information and provided a preliminary system design. Based on this report a final decision was made to complete the design phase by developing a prototype Geo-Database using two commercially available software packages and documenting the results in the Geo-Database Pilot Study – Software Evaluation report. The Work Plan documents, in general terms, all tasks, deliverables, schedules, and budgets for all phases of the Project. Additionally, the Pricing Proposal Section outlined the specific tasks, deliverables, schedules and cost for the Project Phase 1 location.

3.2 Implementation Software

Implementation of the Building Footprint Geo-Database Project augments a mature City GIS, as well as, initiates the "Inception Phase" of one or more new applications by delivering 3D information and improved technology to the City. The GIS user is provided with practical tools and a feasible approach through improvements in new technology that aid in data management, acquisition, and visualization of 3D buildings and other structures. Improvements in ESRI's *ArcGIS* allow an enterprise-wide GIS to manage and distribute 3D spatial information. *ArcScene* and *ArcGlobe* provide a simple but flexible 3D viewing, animation, and simulation interface. These tools can be used to visualize various analyses thru simulation and animation which is an exciting experience for the technical and non-technical end users. The introduction of *Model Builder* in *ArcGIS 9.0* allows for the documenting and execution of complex GIS processes. These complex processes could take days, but once stored in *Model Builder* now can be repeated in minutes to retrieve, clip, analyze, and then setup data in *ArcScene*.

The acquisition of 3D building information is simplified for GIS users by extracting 3D geometry from high resolution aerial photography in a 2D environment. Precision Lightworks' *Nverse Photo* creates detailed textured structures in any standard projection and datum from multiple aerial photographs using basic digitizing skills and simple geometric primitives. Additionally, many export formats are supported which include ESRI's Multipatch Shapefile format. *Nverse Photo* is a plug-in for Discreet's *3D Studio Max,* or *Visio,* which supports the creation of professional 3D modeling environments. Other video software (e.g., Adobe Premiere) can be used to produce professional animations with credits, transitions, and other effects from *ArcScene* or *3D Studio Max*. Leveraging both 3D data and improved technology will result in innovative ways to help meet demands for GIS related services.

3.3 Aerial Photography Acquisition

The minimum imagery requirement for modeling 3D buildings is digital stereo images of the City & County of Honolulu. The overlap between images on the same flight path is at least 60% end-lap. Overlap with parallel flight paths is at least 30% side-lap. Our estimates would call for a flight altitude of approximately 6,000 feet or a photograph scale of 1 inch equals 1,000 feet. Each of the 26 images was scanned at 2,117 dots per inch, each creating 1.2 gigabyte TIFF file size.

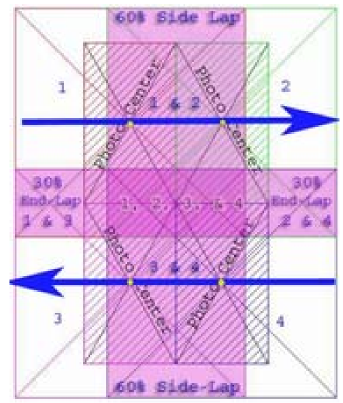

Figure 3-3: Image End-lap & Side-lap Example

Although *Nverse Photo* only requires images that overlap, stereo image pairs ensures a complete acquisition with as few data gaps as possible. Oblique images are preferred, particularly for specific site locations; however, flight paths of just oblique aerial photography could result in many data gaps. Stereo image pairs provide the most economical and efficient means to cover large areas. If cost is not a factor, increase the amount of overlap between images and utilize oblique shots for landmark areas.

Figure 3-4: Phase 1 Acquisition, Image Footprints

3.4 Project Phase Acquisition Area

The areas interest or Neighborhood Boards include Downtown, Kakaako, Waikiki, and Diamond Head. The entire Project building acquisition area spans 7 miles with a width of about 1.5 miles over the core business, financial, and visitor accommodations. Imagery extends from Downtown to Diamond Head as depicted in Figure 2-4. The Phase 1 area, Figure 2-5, was later modified to reduce the number of residential homes and focus on dense apartment and business corridors.

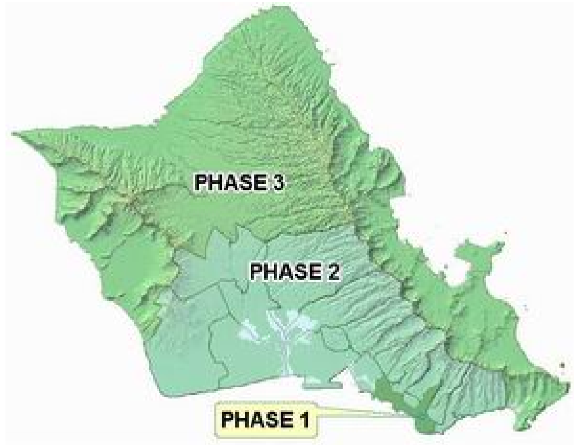

Figure 3-5: Project Phases

3.5 SDTS DEM

USGS Digital Elevation Models (DEM) for Honolulu was used in the SDTS format to define the ground elevation. Building base elevations can either be derived from the DEM or measured from the imagery. Other DEMs can be used if placed in the SDTS format. Ground elevation points were often used within *Nverse Photo* to refine the DEM elevations. SDTS DEM's can be acquired freely from USGS through the GIS Data Depot, (www.gisdatadepot.com).

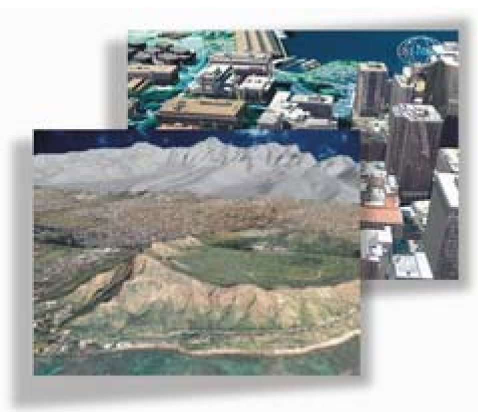

Figure 3-6: SDTS DEM

3.6 Registration of Maps, Images and Cameras

Tie Points and Ground Control Points create registration between images and to City base maps. Square flat shapes are used as tie points in Figure 3-7 and, in practice, are not drawn as part of the modeling; these are maintained in separate files to aid the registration process. Ground Control Points can be used between images, however, maintained separately both in *Nverse Photo* and in *ArcGIS* Geo-Database which is registered to the City base maps.

Figure 3-7: Tie Points and Ground Control Points

Maps of each ground control point are provided in Adobe PDF format, in addition to a ground control point database. Each map locates the site on City base maps, *Nverse Photo* aerial photograph, and a vicinity map of City streets, as depicted in Figure 3-8. The accuracy assessment is scheduled to be completed and will acquire GPS coordinates to associate with the Ground Control Points (GCP). By deriving the GCP from the City base maps instead of using a GPS initially, end users will be able to use the Building Footprint Geo-Database with other City data sets. In this case, relative accuracy is more important than absolute positional accuracy. The GPS coordinates can be applied to the *Nverse Photo* models when the prority for absolute positional accuracy changes. However, the average 3D error is approximately 2.29 pixels or 1.09 feet when registered to the City base maps. Points that vary more than a few feet, as much as 15 feet are either corrected for placement while others are not used. Figure 3-7 shows an enlarged image of a ground control point shown as a purple dot (.) and the location based on the inherent error between controls in *Nverse Photo* as a red triangle (△).

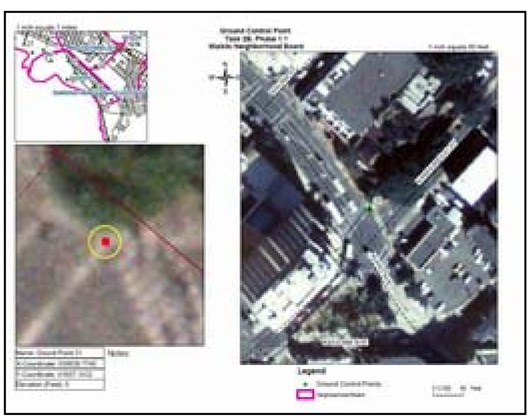

Figure 3-8: Ground Control Point Map

4 MODELING METHODS FOR BUILDINGS

4.1 Modeling Primitives

Buildings are created using simple primitive shapes and require digitizing a polygon on only one image. The primitive shape is automatically transferred to a registered image. Elevation is measured by placing the primitive on the same object located in the adjacent image, Figure 4-1. The object is then extruded to a base elevation, or ground, which is defined by the DEM or from the image parallax.

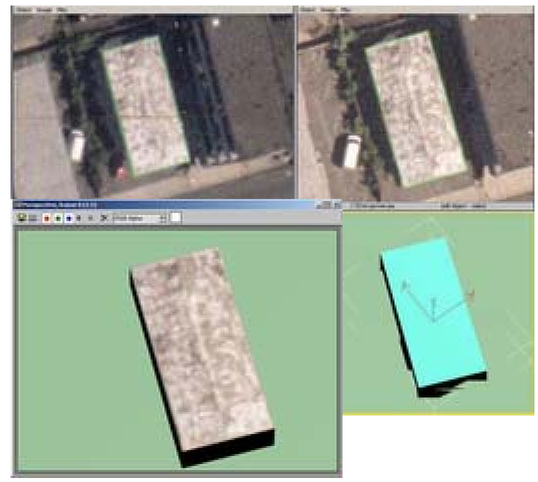

Figure 4-1: Flat Roof Example

The basic primitives include points, lines, polygons, as well as an ellipse. Basic attributes modify the extrusion, set elevation, blend between primitives to create slopes, define diameters for points and lines, create awning or slab effects, and even overhangs for the eve of a roof. Most of these basic attributes have parameters which adjust the actual look of a technique applied to primitives. Primitives, attributes, and parameters in combination result in precise objects that can form complex structures. Complex structures are quite common and can be easily created by users with limited training.

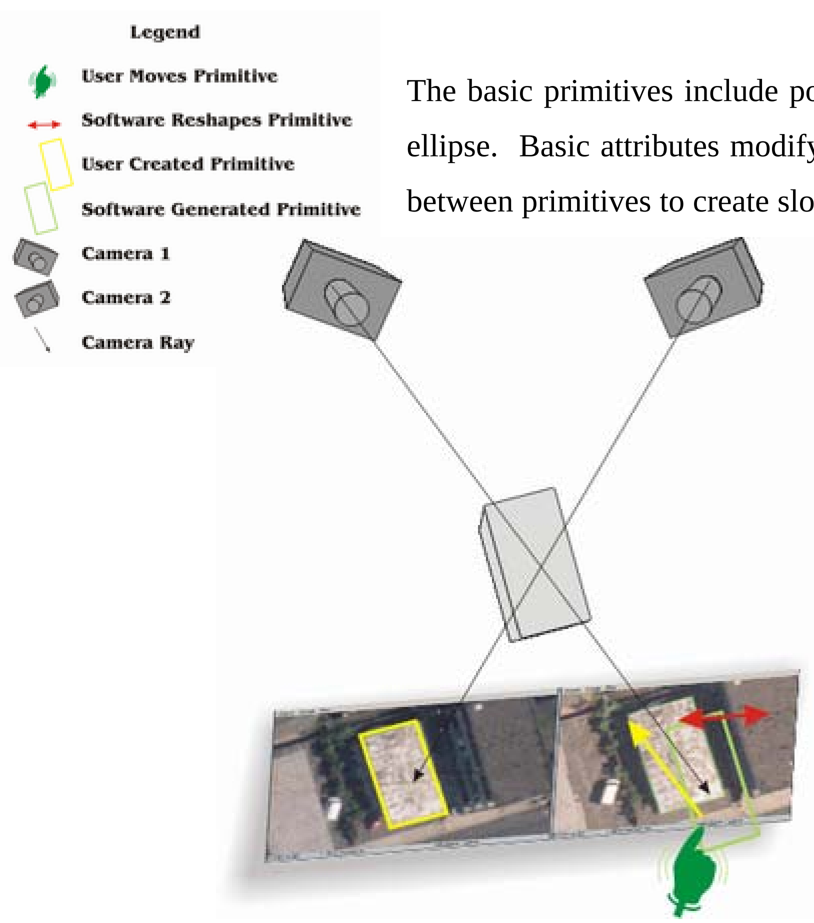

Figure 4-2: Modeling Diagram

4.2 BUILDING TEXTURES

Once a model of a building is constructed, each registered image is used as the source for the model, even if the geometry is not physically on the image. The amount of image side-lap from parallel flight paths and end-lap from sequential camera stations becomes very important. Also, oblique shots can greatly improve the image textures for specific sites. Those buildings that are full or partially obscured in one or more images could still draw textures from additional images.

Table 4-1: Texture Example

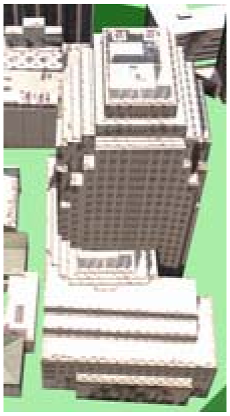

Table 4-2: Obscured Roof

Obscuration of a building in one image by another building can be detected once the geometry exists for the buildings involved. This feature can be used to remove texture mapping errors caused by intervening structures, and can also be used to remove building lean in an orthographic image. This provides for incredible results, however, this feature can be costly in terms of processing time.

ArcGIS 9 MultiPatch objects support image coordinates of *3DS Max* textures. Preliminary testing allow for importing of MultiPatch textured buildings as marker symbols, however, this is not the recommended means to import textures. Some development is necessary before the export of buildings and textures into the new MultiPatch Geo-Database is possible from *Nverse Photo*.

Table 4-3: Obscuration Detected

4.3 GROUND TEXTURES

Ground textures represent a mosaic of Ortho-Rectified images draped on a ground surface defined by the user to provide a seamless appearance to the model. With models that are near the edge of aerial photographs, masking out of the fiducial marks is necessary. Masking prevents large black spots from appearing on the buildings and on the ground.

Additionally, gaps do occur on the ground image in regions that are completely obscured by buildings or not covered by aerial photographs. This can be corrected by overlaying multiple orthographic images to fill in the gaps. Having completed this, some touch-up may still be needed using an image editor like Adobe *Photoshop*.

Table 4-4: Buildings w/ Ground Textures

5 VISUALIZATION

5.1 ANIMATIONS

Once the ground and building textures have been created, the model is nearly ready for animations. Cameras and paths for the camera need to be created. Then it is a simple matter of positioning the camera. USI-Hawaii's animations provide one minute of fly-thru images at 30 frames per second. This requires generating 1,800 still images. Using 3DS Max on a Pentium 4 - 3.2 GHz, with 3.62 GB RAM, it takes approximately 10 to 15 seconds to generate each 640 x 480 frame from a 1,200-building model. The larger the model the more time it takes to render each scene. However, by working on smaller scenes and transitioning animations together, the animations can be made to appear seamless.

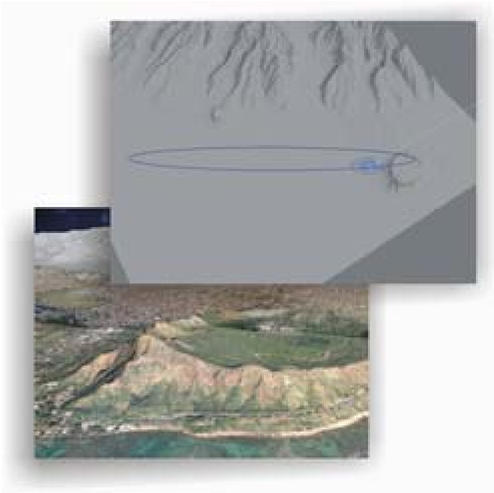

Table 5-1: Camera Path

5.2 Representation of Building Models in ArcScene

5.2.1 Purpose Of Creating ArcScene Projects

The Building Footprint Geo-Database Design Project has an end goal of providing the building models in *ArcScene* projects with defined extents to limit the size of the dataset and enhance performance on the user end. The process for clipping and compiling data for the *ArcScene* projects needed to be repeatable and easily changed to provide multiple *ArcScene* projects for various areas in the Honolulu region. The final product as illustrated in, Figure 5-1, includes a 16 foot DEM, TIN, building models for the study area, 3D cube development, and a clipped Ortho-Photo. The processing of the data is performed in *ArcGIS9 Model Builder*.

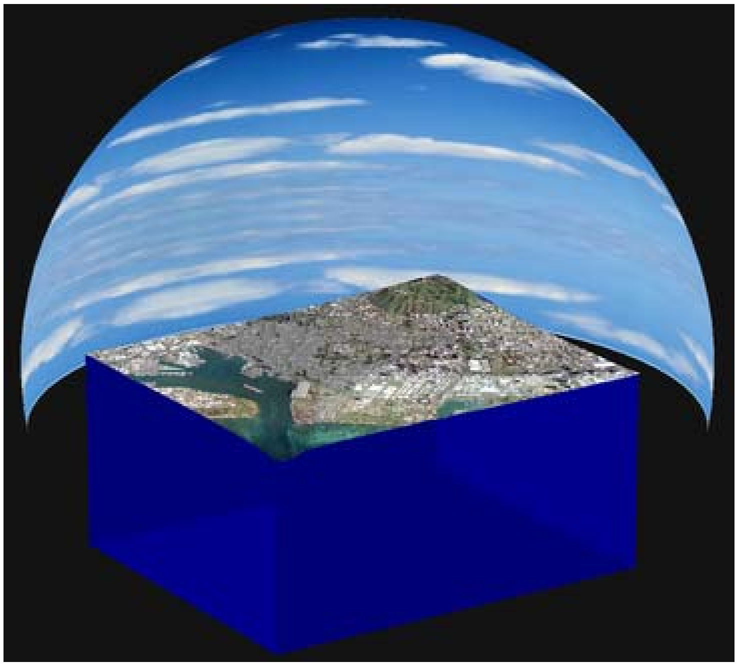

Figure 5-1: ArcScene Project

5.2.2 Creating The ArcScene Projects Using ArcGIS9 Model Builder

The process of producing multiple *ArcScene* projects from multiple large datasets is accomplished using the *Model Builder*. The *Model Builder* application has allowed USI-Hawaii to create a process model that is executable and repeatable. The inputs into the model include a 16 foot grid cell DEM for Honolulu, LIDAR data for the coastline, building models for the Honolulu region, and a large Ortho-Photo for the Honolulu region. The large datasets are processed using *Model Builder* to clip the large datasets to the extent of the defined study area. The study areas for the Building Footprint Geo-Database Project are defined by the neighborhood board boundaries.

The results of the processing are illustrated in Figure 5-2. Where the end product is a 3D area defined by the extent of the request. The process in Model Builder includes clipping the large DEM and creating a detailed TIN from the DEM to drape the Ortho-Photo over. The next step is clipping the Ortho-Photo to the same extent. The final process is clipping the LIDAR data and mosaicing the LIDAR data to the DEM Grid. The result is a seamless grid representing elevation on land and in the sea. The final step is selecting the building in the study area and creating a new 1D, 2D, and 3D representation of those objects. The process takes a few minutes to complete and can be repeated for different extents making the large datasets small enough for the end user.

Figure 5-2: *ArcScene* Downtown Honolulu 3D Cube

6 BUILDING FOOTPRINT GEO-DATABASE APPLICATIONS

6.1 BUILDING FOOTPRINT GEO-DATABASE DESIGN

6.1.1 PURPOSE OF THE DESIGN

The Building Footprint Geo-Database Design is intended to allow the user access to relevant information on the building structures in 3D, 2D and 1D format. The three representation formats enhance the usability of the data by making it functional in the 3D environment in *ArcScene* as well as the 2D and 1D environment in *ArcMap*. The attribute fields in the two dimensional feature class listed in Table 6-1 were established during a series of meetings with the City and County of Honolulu to identify the user needs of the Building Footprint Geo-Database and ensure all relevant attributes were included in the data model.

ID	Field Name	Description	Definition	Source
1	OBJECTID	Object ID	Internal Object Identification	GIS
2	SHAPE	Shape	Geometric entities	GIS
3	Bldg_Name	Building Name	The name of a building	USI-Hawaii
4	FacCode	Facility Code	Land use code for facilities	Land Use
5	FacCodeDsc	Facility Description	Land use code description	Facility
6	TotFlrArea	Total Floor Area	Land use floor area total	Land Use
7	YearBlt	Year Built	Year Building Complete	Land Use
8	TMK	Tax Map Key	9 digit TMK use to link to parcels	Parcel
9	Stru_ID	Structure ID	Auto-generated unique id uses the Neighborhood Board x 10,000 + incremented value	GIS
10	CentLat	Centroid Latitude	Latitude in wgs84	GIS
11	CentLon	Centroid Longitude	Longitude in wgs84	GIS
12	Perimeter_GIS	Shape Length	Perimeter of polygon	GIS
13	Area_GIS	Shape Area	Area of polygon	GIS
14	Bldg_Hght_GIS	Building Height	Calculated from the 3D Building model	GIS
15	Floors	Floor Count Above Ground	This is the number of floors in a building above ground.	Land Use
16	SourceInfo	Source Information	Source Name: Source Type: Acquisition Date: Notes	USI-Hawaii

Table 6-1: Two-Dimensional Feature Class Attributes

6.1.2 DESIGN

The Building Footprint Geo-Database is designed to provide the City and County of Honolulu with optimal performance when querying and editing data. The geo-database is composed of three feature classes: StructureCentroid(Feature

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Point), StructureFootprint(Feature Polygon), and StructureMultiPatch(Feature MultiPatch) as illustrated in Figure 6-1. The central feature class in the model is the StructureFootprint representing the two-dimensional footprint of each structure. The StructureMultiPatch and StructureCentroid feature classes are related to the StructureFootprint using a relationship class with a one-to-one cardinality between objects as illustrated in Figure 6-1. The unique identification number between the objects is a number generated during the pre-processing of the data. The structure that has been created allows the user to access data stored in the StructureFootprint using any of the three feature classes. This format allows the user to access the data in ArcScene using either the two-dimensional StructureFootprint or the three-dimensional StructureMultiPatch.

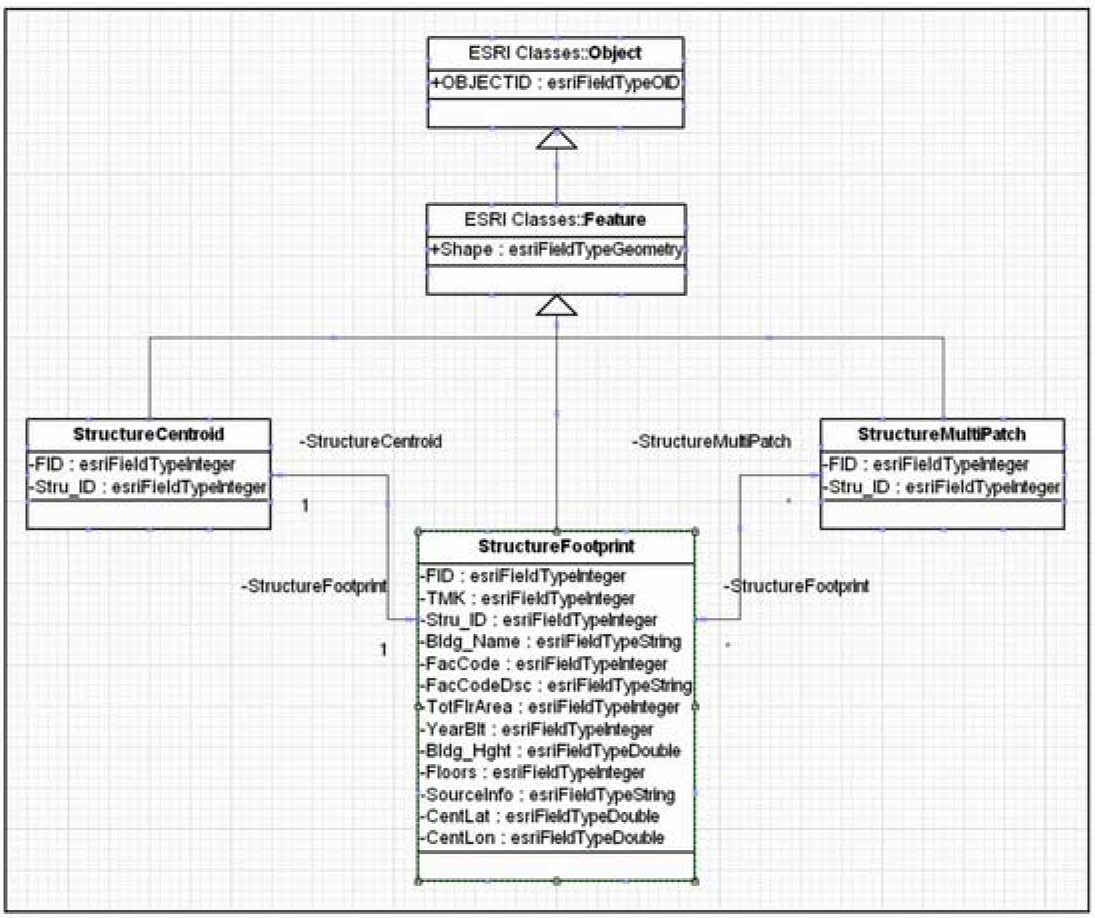

Figure 6-1: *Visio* Geo-Database Model

6.2 ARCGIS 9 APPLICATIONS

6.2.1 IMPROVED DATA PROCESSING USING MODEL BUILDER

The release of *ArcGIS9* has enabled the streamlining of data processing and data integration. To complete the Building Footprint Geo-Database outputs from *NVersePhoto* need extensive editing to prepare the shapefiles for import into the geo-database repository. This data processing is accomplished using the *Model Builder* in *ArcGIS9* as illustrated in Figure 6-2. The processing time using the *Model Builder* has been greatly reduced and data integrity improved.

The *Model Builder* processes the two-dimensional shapefile produced in *NVerse Photo* by adding necessary attribute fields, performing field calculations, joining data to the StructureCentroid feature class and the StructureMultiPatch feature class using a spatial overlay, deleting unnecessary attribute fields, and joining data from database tables. Prior to *ArcGIS9* the data preparation was based on a conceptual flow model diagram. The processing took several days, however with *ArcGIS9* the data preparation takes a few hours. The final output is imported into the Building Footprint Geo-Database. The utility of this tool has greatly improved accuracy of data integration and time efficiency.

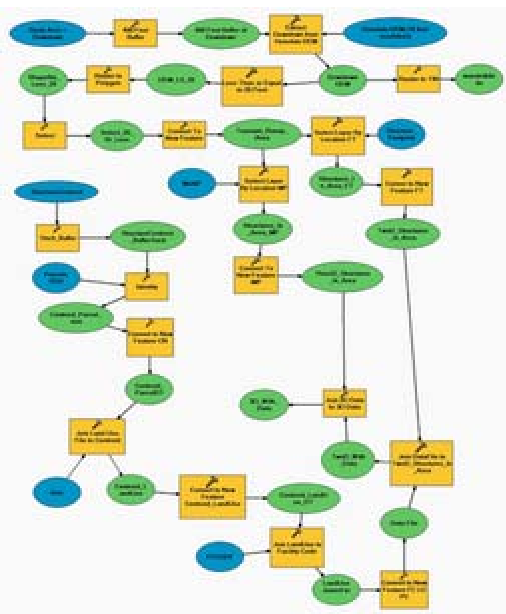

Figure 6-2: *ArcGIS 9* Model Builder Diagram

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7 CONCLUSION

The technologies outlined in this paper demonstrate the growing potential for three dimensional representation of the world. The ability to accurately represent building structures in three dimensions with real textured facades demonstrates advancements in computer software and technology that was not practical or cost effective. The integration of database formats such as the ESRI Geo-Database with three dimensional textured building structures provides the user with a dynamic representation of their area of interest allowing them access to pertinent information about each structure in the model.

Interactive urban models such as the one outlined in this paper provide urban planners and developers with tools to make informed decisions. The ability to model re-development areas represents one of many application of this technology. The models that are being developed will also further support necessary City services for land use planning, tax assessment, construction permitting, utility management, homeland security, and other major programs. The integration of large datasets into models such as those outlined in this paper will also allow emergency response technicians the ability make informed decisions in the field where life is at stake.

The ability to represent the world we inhabit in realistic three dimensional models connected to large databases is at the forefront of this new and emerging technology. This project demonstrates the ability to capture architectural details from high resolution images that are then linked to other enterprise level information system components. Future capabilities will need to provide flexible 3D viewing tools capable of providing realistic urban simulations. This can possibly be delivered via the development of thin-client interfaces that run on field computers bringing technology into the hands of emergency response technicians and infrastructure managers to increase informed decision making.

8 ACKNOWLEDGEMENTS

Special Thanks to USI-Hawaii staff for long hours and eye candy images:

L. Michele Sato – Animator, Graphic Artist, & Systems Analyst

Janna Cole – 3D Modeler

Special Thanks to City & County of Honolulu staff:

Jon Hodge

Mark Lierman

9 NOTES

USI-Hawaii recognized for excellence in Design Services

May 25, 2004 - The American Council of Engineering Company's – Hawaii held their Annual Symposium where the Department of Design and Construction of the City & County of Honolulu presented their awards for recognition of outstanding consultants. USInfrastructure-Hawaii received a Certificate of Appreciation for Design Service, which acknowledged outstanding service provided to the Department of Planning and Permitting of the City & County of Honolulu. The award of this certificate was based on the quality of USI-Hawaii's work, exceptional responsiveness, communication, ability to work under changing direction, and submittals of thorough and innovative assessments that have been instrumental in the continued development of the City and County of Honolulu's Geographic Information System (GIS). Services provided to Honolulu's GIS include the development of a Geo-database design and feature dataset of 3-Dimensional Building Structures for the Honolulu Primary Urban Corridor, the data conversion of Storm Drainage Facilities, and strategic planning of GIS initiatives.

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Steven E. Hochart is married and lives in Kailua on the island of Oahu. He works for USI-Hawaii providing GIS services to clients. He has been providing GIS services in Hawaii for the past 3 years. He received a Bachelor of Arts degree in Geography in 2001, from the University of California at Santa Barbara. Steven was raised in Pacific Beach, San Diego California where he grew up sailing and competing in races nationally and internationally. Prior to working at USI-Hawaii he worked for The University of Hawaii on the Hawaii Gap Analysis Project. He is currently working on his Masters Degree at the University of Hawaii, Department of Urban and Regional Planning.

Ken Schmidt is the GIS Coordinator for the City & County of Honolulu and has over 20 years of experience in developing and managing GIS and related computer technologies. He is responsible for defining the City-wide GIS programs strategic plans, goals and objectives. He also provides technical oversight for the design, implementation, and operations of a client-server computing system that tracks and manages data relating to City construction and development permits. Additionally, he is the supervisor for the Honolulu Land Information System. His background includes production of wetland maps using an analytical stereoploter, a GIS Analyst for the Suwannee River Flood Protection Program, and the Southwest Florida Water Management District.

Mr. Cadieux is currently a Vice President, for US Infrastructure-Hawaii, Inc. located in Honolulu. He has more than 20 years of experience in all phases of the project and construction management process on major national and international transportation, infrastructure and GIS projects. Alan has extensive experience in business development, startup and management of a business unit/office including planning, financial management, human resource management and corporate reporting, bidding process, fee negotiations, project startup and oversight, quality control and client interaction and job satisfaction. Alan has led the startup of five successful offices both nationally and internationally.