# A Comprehensive Multilevel Modeling Method for the Establishment of 3D and Virtual Reality GIS

Yongping Zhao
Amani AlOthman
Hanan Alhashash
Mostafa Kawiani

Kuwait Institute for Scientific Research
P.O. Box 24885
13109 Safat
Kuwait
Tel: 965- 4989738
Email:yzhao@kisr.edu.kw

**Abstract**

Three Dimensional (3D) and Virtual Reality (VR) GIS is one of the interested research fields for environment related applications. As the fact that huge data and information should be processed in order to establish a 3D and VR oriented GIS, the related applications did not get too much progress.

Kuwait has much geospatial related data resources which were collected by different ministries and agencies. Those databases include remote sensing images, aerial photos, and GIS datasets. Due to the limitation of geospatial hardware, software, technology, manpower, and system implementation methods in processing of those resources, much of the data are still stored as raw information or simple GIS datasets. Clearly, the plentiful data resources might be used for 3D and VR GIS modeling which may serve almost every government department and private company.

In this paper the authors presented a Comprehensive Multilevel Modeling (CMM) method for the establishment of 3D and VR GIS system based on the environment of Kuwait Administrative distribution. The Multilevel 3D and VR GIS method is divided into 5 levels which are national, regional, local, objective, and internal level. According to the CMM method, a 3D and virtual GIS system can be implemented by different groups with very fast speed.

In the research, the authors selected Kuwait City residential area and the south of Kuwait which cover more than 1,000 square kilometers as an experimental place for the test. Different GIS datasets, remote sensing images, and stereo aerial photos were collected as the original data resources. By the analysis of the data quality and possible application trend, a 3D and VR GIS which includes the detail features of Kuwait Institute for Scientific Research (KISR) main campus and one of a public interested place of Shark Mall was established. The system has the functions for displacing and analyzing 3D and VR geospatial information from CMM national level to internal level.

Clearly, CMM is an efficient method for the establishment of 3D and VR GIS system. The method is being used by the authors to establish the national 3D and VR GIS system.

Key Words: CMM, Photogrammetry, GIS, 3D, Virtual Reality, Modeling

## 1. Introduction

Three dimensional (3D) and virtual reality (VR) geographic information system (GIS) has demonstrated strong application requirements for city planning, transportation management, emergency response, and environment related decision making (Kwan and Lee, 2005). The 3D geometry features which were included by GIS could supply geospatial dimensional information for decision makers. The VR objects in GIS could help people to get comprehensive understanding of environment issues. The integrated 3D and VR system could also supply spatial based analysis functions by combining plentiful 3D objects' attribute information. Apparently, the advantages of 3D visualization information are impossible to be rivaled by traditional 2D GIS model.

Actually, 3D and VR GIS model is very expensive to be established by traditional technologies (Yongping Zhao, et al, 2000). It is constrained by series procedures such as high resolution aerial photos (remote sensing images) acquirement, ground control points collection, 3D modeling, geometry features extraction, and the 3D and VR information representation. Each procedure that needs digital photogrammetry, remote sensing, surveying, GIS, and 3D visualization technologies should be performed by professional people. Therefore, high resolution 3D GIS modeling is recognized as a luxury geospatial product which is still pending for efficient scientific solutions. This situation is the same even for small country such as Kuwait where only the small scale 2D GIS is prevailed in using (Dirk Hermsmeyer, et al, 2005.).

Several methods have been used to establish 3D GIS which produced impressive results. For example, Kolbe and Groger (2003) have defined different levels of detail (Lod) which were used to construct a 3D city model; Altmaier and Kolbe (2003) tried to construct an interoperable architecture for 3D geo-visualization based on their 3D project; and OGC developed Geography Market Language (GML) to define 3D GIS modeling profile (OGC 2003). Anyway, the researches were either focused on 3D objects themselves or only considered how to design methods to satisfy projects' requirements. It is hard to use the similar methods for fast implementation of large scale 3D and VR GIS modeling.

Some popular GIS related software such as ArcGIS, ERDAS, and AutoCAD has supplied special functions to process 3D and VR information. For example, ArcGlobe can be used to display 3D and VR GIS information in a global dimension; ArcScene can be used to edit and analyze 3D GIS features with integration of other GIS layers; Imagine VirtualGIS includes plentiful VR GIS analysis functions; AutoCAD can be used to process 3D and texture information. However, all of these packages are based on some assumptions which most of 3D and VR information should be created by professional data products providers. The packages themselves are only used to display and analyze 3D and VR GIS information. Evidently, they are unrealistic assumptions where high resolution 3D datasets are insufficient in reality.

In later of 2004, the GIS team in KISR began to investigate a method for establishing 3D and VR GIS model with digital aerial photogrammetry and GIS technologies. The first experimental 3D and VR GIS model was established in March of 2005. It is a KISR main campus based 3D GIS model (Figure 1). The included 3D features such as buildings, roads, grasslands, parking lots, and boundary were extracted from stereo model which was established by the support of high resolution aerial photos and accuracy ground control points (GCPs). It was an initial success in the exploring of Kuwait 3D GIS modeling method (Yongping Zhao, et al, 2006). Later, the team extended the experiment to Kuwait city residential area and the south desert area of Kuwait which cover about 1100 $km^2$ terrestrial land. By series experiments, a Comprehensive Multilevel Modeling (CMM) method was developed by the authors. This method can be used to establish 3D and VR GIS model efficiently in small countries such as Kuwait.

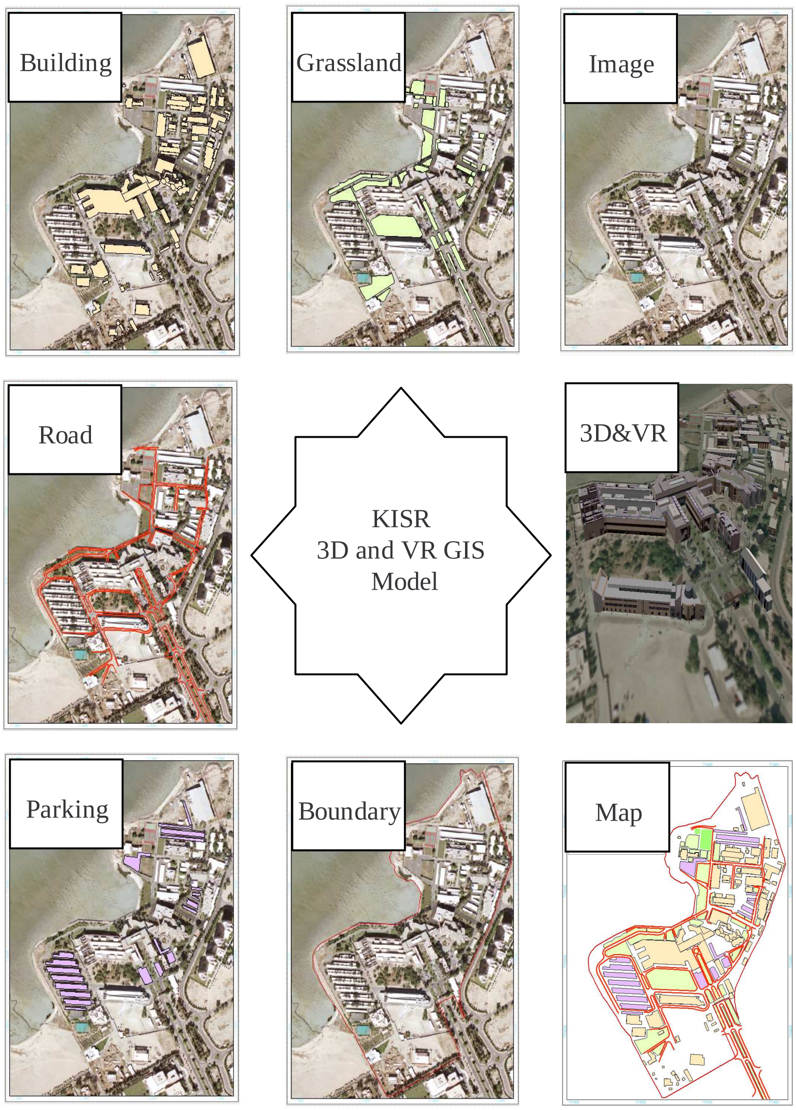



Figure 1. KISR 3D and VR GIS Model

## 2. Requirement of High Resolution GIS Datasets in Kuwait

Recently, Kuwait has had tremendous changes which were leaded by city planning and road reconstructing. Many new buildings have been established and the highways reconstruction has also got much progress. At the same time, Kuwait e-Government strategy has demonstrated fast development by the support of government and IT technologies. This supplies an active development stage for GIS, photogrammetry, and remote sensing related geomatics technologies in supporting government decision making.

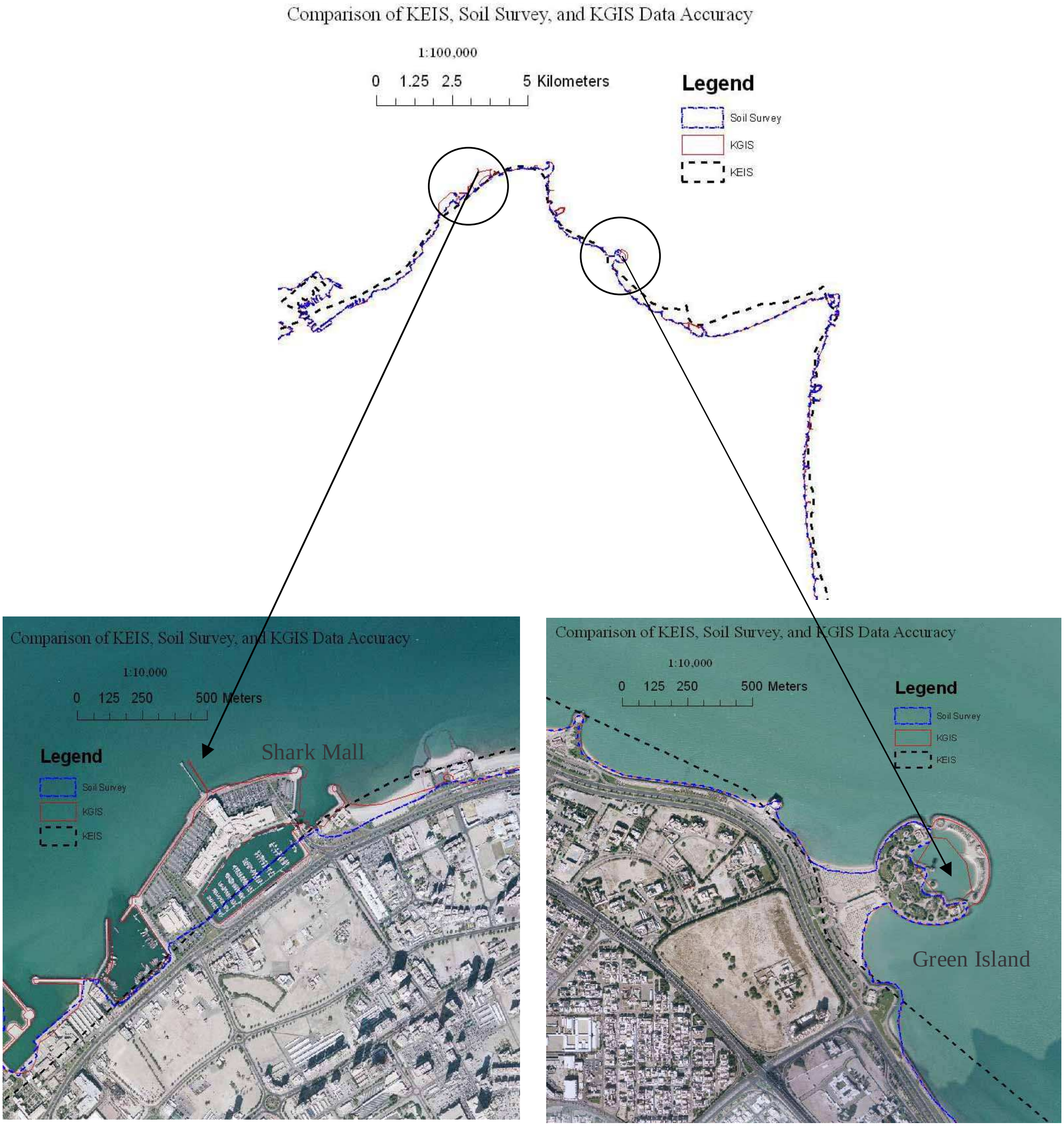



Figure 2. Comparing the boundary accuracy of KEIS, Soil Survey, KGIS, and the Orthoimage databases in Kuwait Shark Mall and Green Island areas.

However, Kuwait current scientific based GIS datasets have drawbacks in supporting the related high resolution geospatial applications. The current GIS databases were established with lower scales base maps and were digitized by different agencies. The nonstandard designing procedures might result in confusion when using the systems. Figure 2 is the comparison of Kuwait Soil Survey GIS datasets (Grealish, etc. 2005), Kuwait Environmental Information System (KEIS phase I and KEIS Phase II) (Abdul Nabi Al-Ghadban, 1997), and Kuwait Basic GIS Datasets or Kuwait GIS database (KGIS) which are being used in KISR. In order to compare the errors which are existed in the systems, a high accuracy image database was established by the authors. By the comparison of the boundary information in Figure 2, we could find even for KGIS which has the advantage on accuracy in comparison with Soil Survey and KEIS databases, the non systematic errors are still existed in the boundary layer. If the data scale was enlarged to 1:10,000, the errors in the zoomed in places of both Shark Mall and Green Island can reach to 50 meters if they are compared with the image database.

According to the results of the conflict between the increasing application requirements and the weak of current GIS databases, a high resolution GIS database should be designed to support the increased market requirement. In the late of 2003, the high resolution aerial stereo photos which cover Kuwait terrestrial environment were taken by the cooperation of Kuwait Municipality and SwedeSurvey. The photogrammetry scale was 25,000 which the pixel resolution could reach to 38 centimeter. It is a plentiful geospatial information resource that may be used for extracting unlimited geometry related information. At the same time, different agencies such as Kuwait Institute for Scientific Research (KISR) have launched several new projects which are using high resolution remote sensing images such as QuickBird and IKONOS information for environment related research. All the high resolution imagery information provided us a possible opportunity to develop a new 3D and VR GIS system for geospatial applications. The CMM method was developed under this circumstance to leverage the market requirements and the increased geospatial technologies.

## 3. CMM Architecture

Comprehensive Multilevel Modeling (CMM) method for 3D and VR GIS was defined by the support of Kuwait 3D GIS Modeling pilot project. It is a systematic method which was designed for fast establishment of 3D GIS model with less expense in small countries such as Kuwait.

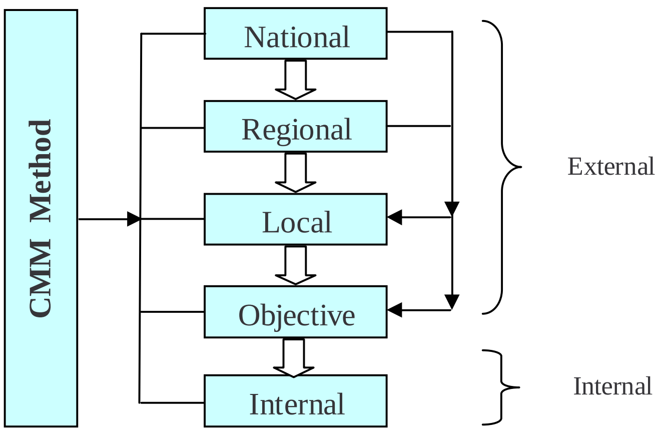



Figure 3. CMM 3D and VR GIS modeling structure.

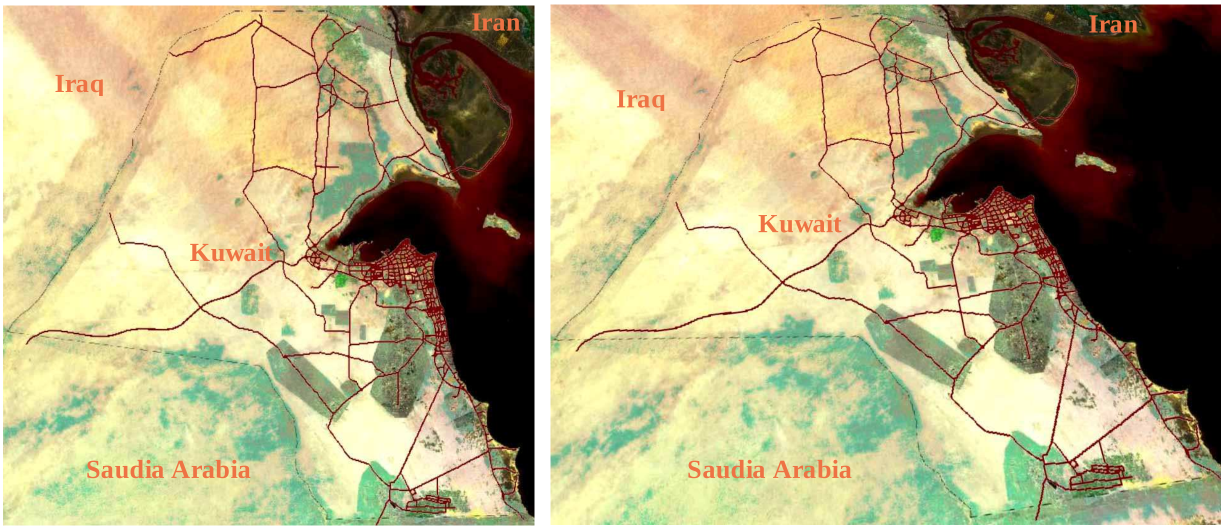
The CMM method was divided into national, regional, local, objective, and internal levels to construct a national 3D and VR GIS model (Figure 3). The national level is focused on the process of lower resolution datasets in geodatabase and the internal level is to process the highest accuracy geometry information in 3D GIS modeling. The 3D and VR GIS modeling procedures may follow the hierarchy structure from national to internal level or use the overlap method to jump down from any higher hierarchy to the third or fourth level.

The CMM method can also be concluded as external and internal structure. The external structure includes the national, regional, local, and objective levels and the internal structure includes only internal level. This classification supplies a clear clue for users to define their 3D GIS modeling requirements and aims before start any projects.

### 3.1 National

The National level of CMM method is located at the highest hierarchy in a national 3D GIS modeling structure. The geometry information in this level includes lower resolution remote sensing imagery such as Landsat and Spot images, GIS outline layers such as boundary, main roads, and administrative regions, digital elevation model (DEM), and the related attributes information. The map scale included in this level is below 1:100,000.

National level 3D GIS information mainly supplies the bird viewing of the national wide geographic information. It shows the general outline that helps decision makers to have a comprehensive understanding of the national resources. This relative lower accuracy information may be used for environmental analysis and planning in national level.




a. 2D image and road information b. 3D image and road display

Figure 4. Information representation at National level

Figure 4 is Kuwait 3D GIS model represented at the national level. Figure 4a is a 2D representation and Figure 4b is a 3D representation of the same environment. The integrated boundary, road, and remote sensing imagery information could show the national general resource and environment information. Attributed to the contribution of remote sensing images, the neighbor countries' environmental information near Kuwait could also be represented easily by the system. This is helpful in processing boundary related information.

The image dimensional information included in 3D GIS model should be little bigger than the investigating or modeling area. This is owing to 3D display where more wide space is needed to acquire a fully showing of the environmental relationship.

### 3.2 Regional

Regional level is defined based on administrative sections. The information included in this level is interested by managers who want to know the resources related to their administrative regions, such as a region of a county or the combination of counties – for example a province or a state. The imagery information in this level should have the accuracy for region related decision making such as residential planning, population migration analysis, transportation management, and emergency response etc. As low resolution remote sensing imagery is not enough for the related analysis, high resolution remote sensing images (such as IKONOS and QuickBird images) and aerial photos may be used to help the decision making.

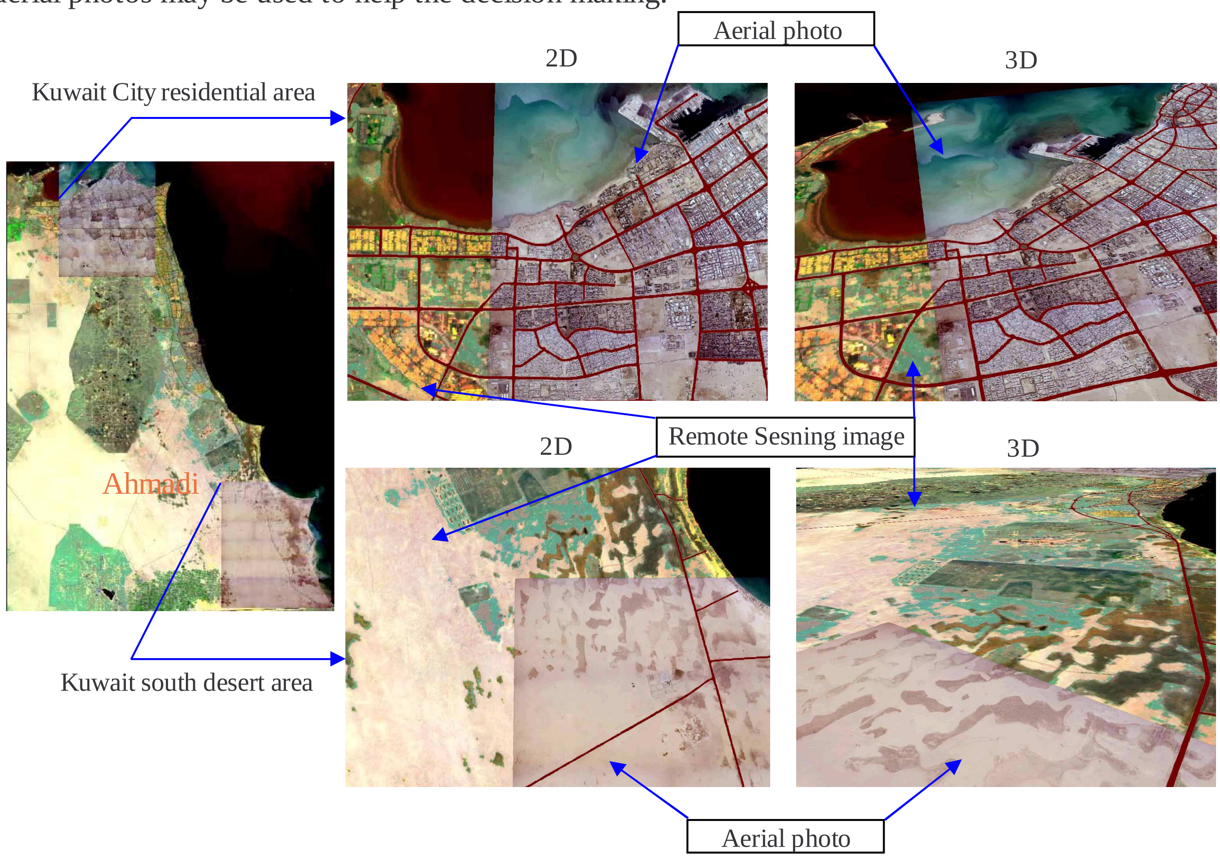



Figure 5. Information representation at Regional level

GIS features such as roads, administrative boundaries, and typical landmarks are helpful at this level. The regional database related to population, houses, schools, banks, and hospitals are also needed for further analysis. By the combination of GIS features, images, and database information, the 3D GIS model could help decision makers to acquire more detail resource information by quantitative analysis in a 3D environment.

The geometry information in this level is based on national or regional basic maps. The original mapping scale which doesn't exceed 1:25,000 is good enough for the related application requirements. GIS database at this scale may already or partly be created by national georelated agencies. The role of 3D GIS model at this level is to give a more detail bird viewing of the environmental relationship and the terrestrial changes analysis of the regional land.

Figure 5 is the illustration of Kuwait 3D GIS database where remote sensing images and aerial photos were used together in 3D GIS modeling. The remote sensing images are the heritages which came from the national level in CMM structure. After the visualizing scale of 3D data reaches to 1:100,000 or higher, aerial photos and high resolution remote sensing imagery will be used to display more detail information. If the aerial photos in some regions are still missed, the lower remote sensing images are the alternative option.

### 3.3 Local

Local level is defined to bear the creation of more reality 3D and VR GIS system. 3D buildings and DEM information at this level will be used for quantitative analysis and decision making. The geometry information of 3D objects should be extracted by special survey method such as digital photogrammetry. Public interested buildings and objects may be texturized with the corresponding facets photos.

a. 3D GIS represented in local level with detail objects.

b. 3D GIS represented in local level with selected objects.

Figure 6. Information representation at Local level

The mapping scale of 3D and VR GIS system at local level should be from 1:2,000 to 1:25,000. According to mapping accuracy requirement, 3D objects extracted by photogrammetry technology could match the precision. This means photogrammetry technology will play the key role in extracting 3D objects for 3D GIS modeling. High resolution remote sensing images and aerial photos will be used as geometry information resources.

Figure 6a and 6b are 3D objects represented in Local level. Figure 6a includes all 3D buildings in KISR main campus. The 3D objects can be used for precise spatial analysis and application. The information may also be used for KISR environment planning and engineering application. For example, it has been used for KISR network manholes mapping and distribution analysis. Figure 6b includes a part of 3D buildings of Kuwait city. This situation will happen in any Local based 3D GIS constructing project where only part of 3D objects may be modeled. Owed to the lack of manpower and financial support, 3D GIS modeling may cover a part of 3D objects of the researched local area.

Local level 3D GIS modeling projects may be requested by local governments or agencies where 3D GIS will be used for their engineering planning and environment management, such as KISR 3D GIS model. Especially with the development of widely usage of internet and intranet technology, more and more agencies will focus on campus based 3D and VR GIS modeling. The development trend will encourage investigators to create more useful 3D GIS models.

### 3.4 Objective

Objective level contains the highest accuracy in external 3D GIS modeling. It is a key procedure where high accuracy and reality 3D objects will be designed. The visualization effect of 3D GIS will be directly decided by the designs during this level.

a. Complicated 3D and VR GIS objects with texture information.

b. The complicated huge 3D objects

Figure 7. Information representation at Objective level

3D objects in Objective level will be created by the combination of photogrammetry and survey technologies. Some complicated objects such as the cone structure in Figure 7a (the upper left) and the multilevel structure in Figure 7a (the lower left) are difficult to be extracted from stereo images. Those 3D objects should be created with additional edit work after the sketch structures were extracted. By further design and attachment of textures information, the more reality 3D objects will be created and integrated to the GIS model.

Some existed 3D objects or buildings' designing maps may be used for the implementation of 3D GIS modeling at Objective level. If the related designing or engineering maps could be acquired, the georeference information should be allocated to the corresponding points. After the 3D model is constructed, the accuracy of the objects should be verified by field surveying. 3D maps may also be combined with photogrammetry technology to create more useful 3D GIS model. Although the objects accuracy may be lower than CAD designing or large scale surveying technology acquired ones, it is good enough for 3D GIS modeling.

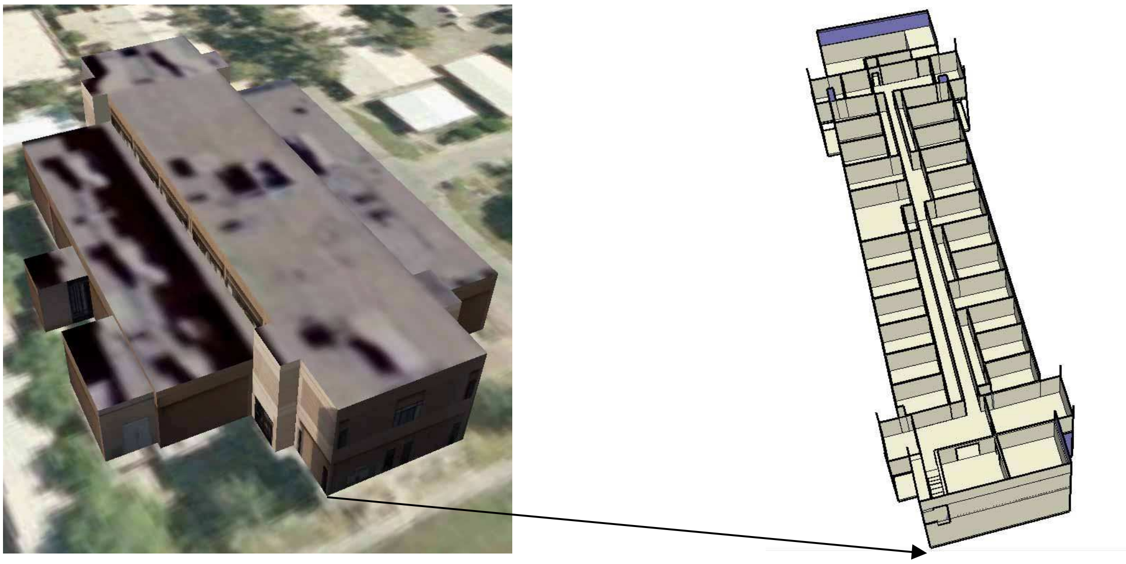
The mapping scale for 3D objects at Objective level should be large than 1:2,000 and may reach to 1:500 or higher. Figure 7b is an example of 3D object at Objective level. The building is one of the popular shopping centers named Shark Mall in Kuwait city. It is a huge 3D object in comparing with Figure 7a where several small objects were displayed. Apparently, the extracting and editing task for 3D objects may be various from size to shape. It needs an efficient cooperation among different groups to perform the modeling work.

### 3.5 Internal

Internal level is a procedure to create the inner structures of objects in 3D GIS modeling. The similar technologies were previously owned by CAD companies such as AutoCAD. However, the internal structure is important for 3D GIS applications such as in disaster response (put out fire inside buildings) and resources management (gas lines distribution inside buildings). By the integration of GIS and CAD technologies, the internal structure may be represented by 3D GIS model.

The inner structure of 3D object is very difficult to be acquired. The information must be created by surveying technology or extracted from original engineering drafts. This is an expensive but very interested GIS application field. By the integration of internal 3D object's structure, GIS models may be used from general environment based applications to office routine management. The telephone lines, office positions, utility lines, and most locations based information can be managed by 3D GIS.

Figure 8b is the internal structure of the middle part of the building showed in Figure 8a. The offices, doors, and stairs are clearly represented by the 3D GIS model. The inner structure of the building demonstrated more information if the GIS model were employed for disaster response or other applications such as house management.



a. 3D object.

b. Internal structure of the 3D object.

Figure 8. Information representation at Internal level.

## 4. Example of CMM Implementation

According to the CMM method, 3D GIS modeling should be planned systematically from top level to low level. Most of the datasets' creating and editing work in lower level can be shared by different groups after the quality control is used. In order to ensure the implementation of 3D GIS model, some basic hardware and software are required if the modeling work is finished by a specific agency or unit.

Digital photogrammetry workstation is the required hardware in order to extract 3D features. All the following datasets quality will be directly influenced by the accuracy of stereo models constructed at this step. Digital photogrammetry package and remote sensing software are needed in order to process huge imagery information and to create mosaicked imagery database.

Global Positioning System (GPS) receivers and Total Stations are necessary to get ground control points (GCPs). Although digital photogrammetry technology may help to decrease huge field survey work, some basic GCPs are required in order to restore the precisely stereo model for 3D features extracting. They are also important for the model accuracy test after adjustment technology is employed. In addition, more precisely 3D features are needed to be acquired through the surveying equipment.

GIS package is the basic platform to manage 3D GIS features and attributes information. It should include 3D scenes and virtual reality representation and analysis functions. After the 3D features are obtained, the related information will be integrated to GIS platform for further process. Geodatabase technology will be used to store and handle the massive datasets.

Graphics design and edit software is one of the complementary components for detailed 3D objects design. This function will be used at Objective and Internal levels where more reality 3D objects designs are needed. It is a crucial package for creating specific 3D objects with multilevel features. It can also be described as a decorative stage for the visualization effect of 3D and VR GIS model.

Mandatory software tools for developing compulsory packages are also vital to implement 3D GIS model. Owing to the fully usage of GIS, photogrammetry, remote sensing, GPS/TPS, and CAD technologies, it is hard to share dataset formats among them. Therefore, some packages should be designed to convert and integrate datasets from one platform to another. Other second development tools are also needed to construct and refurnish 3D GIS model. They will be based on commercial packages which have been used for specific projects.

Figure 1 and the other several figures which were used in this paper have shown some products created from the 3D Modeling Pilot project which was finished in Kuwait city. By the fully using CMM method, a 3D GIS system has been constructed from national level to internal level. The test places included more than 1000 square kilometers in Kuwait city and the south of Kuwait. Different GIS datasets, remote sensing images, and stereo aerial photos were collected as the original data resources. The hardware and software of ArcGIS, Leica Photogrammetry Suite (LPS), ERDAS Imagine, and Leica GPS/TPS were all used for the data creating and 3D modeling. Several data converting and 3D GIS refurnishing tools have been designed to enforce the system functions. As the result, a useful 3D and VR GIS experimental model was established in Kuwait.

Clearly, CMM method has the advantage for fast establishment of 3D GIS models to match different requirements. It was created by the implementation of Kuwait 3D GIS Modeling pilot project and is being used for Kuwait 3D GIS Modeling project which extends the research area to the national wide. By defining the data resources and the functions which should be finished in each CMM level, the national 3D GIS model could be implemented by efficient cooperation among different groups.

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