The Design and Development of a Virtual 3D City Model

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ABSTRACT

Modeling objects for 3D descriptions of the real world have been useful for many urban applications such as planning, construction and representation of the urban sceneries. Buildings, roads, trees and terrain are considered as the most important objects in producing a 3D city model particularly for the creation of virtual environments. 3D city model is basically a computerized model or digital model of a city. This paper considers important stages involved in creation of 3D city models, which includes reconstruction of buildings, landscape and urban settings that are relevant in urban and environmental planning. The platform used in the creation of a virtual 3D city model has been provided by the GIS environment and assisted by an affordable off the shelves photograph aided modeling and 3D modeling software. The emphasis is placed on the use of aerial and terrestrial photographic techniques and the existing topographical map data. Though the technique has been available for few years, the technology is still at an experimental stage in Malaysia. Therefore, this study is hoped to become as a reference in the creation of more virtual cities throughout the country.

1. Introduction

The needs for 3D city models are growing and expanding rapidly in various fields include urban planning and design, architecture, environmental visualization and many more. The efficient generations of the 3D city models are improving the practice of urban environmental planning and design. For example, planning authorities will be able to illustrate explicit photo-textured information of what the city environment will look like after a proposed change. Photo-textured and three-dimensional models enable easy understanding. It is relatively easy to layer abstract phenomena over a detailed model. User would be able to recognize specific elements, spatial position, scale, and to relate plan details and other information within the area under investigation. The computational power of this technology to transform and instantly compare alternative representations provides decision-makers with unprecedented flexibility. When and if visualization tools and good data are widely available, one will be able to propose changes to a city without a dialogue that includes a systematic investigation of the visual implications of a design.

There are various terms used for 3D city models such as "Virtual City", "Cybertown", "Cybercity", and "Digital City". Clarification for all terms has been made by Dodge *et al*. 1998.

3D city models are basically a computerized or digital model of a city contains the graphic representation of buildings and other objects in 2.5 or 3D. The term 2.5D is used for describing models where there is only one unique Z-value (elevation value) defined for each pair of XY-coordinates (Sinning-Meister and Gruen, 1996). However, some type of objects like CAD models or solid models can be represented as 3D. The most important characteristic of 3D city models are the possibility to navigate through the model by walking, flying and examining (Bourdakis, 1997). Walking means moving on the model surface, flying has three dimensional freedom of movement and examination is a view where the entire model is visible in the view port and the user is free to rotate the object in three dimensions. 2.5D visualization and 3D visualization have static predefined viewpoint and users only move the object rather than engage into the environment. The highest form of visualization is using virtual reality (VR) technology. VR offers new technique for visualizing 3D city model. This is the reason why virtual 3D city model term is used instead of just a 3D city model. By using the VR technology, navigating through the model is just a piece of cake. The environment where this model consists is known as virtual environment (VE). A virtual 3D city model can be viewed on a computer screen, projected on a large screen or with head mounted displays (HMDs).

2. A gallery of 3D city models

One of the earliest examples of 3D city model is the Bath Model (Bourdakis and Day, 1997) shown in Figure 1. This model was developed by the team of researcher at the Centre for Advanced Studies in Architecture (CASA) University of Bath, UK.

Figure 1. The Bath model (Bourdakis and Day, 1997)

The reviews of 3D city models that have been made by Batty *et al*. (2000) stated that there are over 60 large-scale 3D city model projects worldwide each of which modeling a part of an existing city (Figure 2). The two best developed sets of applications that they found are in Tokyo (Figure 4) and New York (Figure 5). Most of the 3D city models were being developed for a very wide range of applications. Batty *et al.* 2000 define these into 12 different categories of use. Shiode 2001, refine this further into four different general categories of use, 1) planning and design, (2) infrastructure and facility services, (3) commercial sector and marketing, and (4) promotion and learning of information on cities.
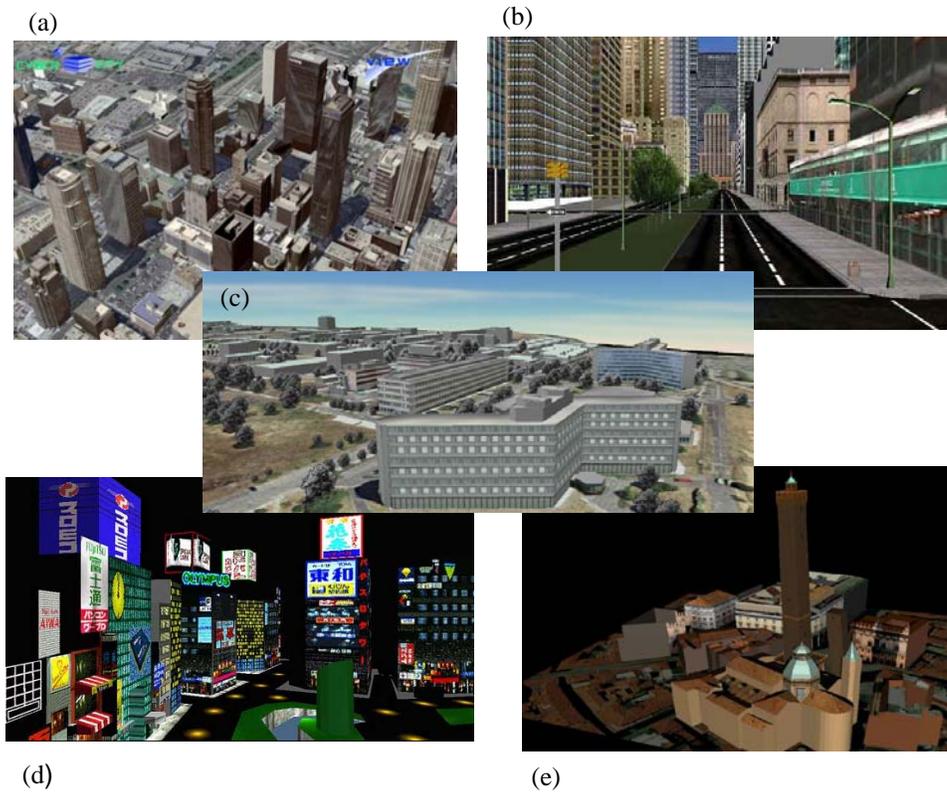
Figure 2. Examples of 3D city: (a) Virtual city of Los Angeles (cybercity.tv, 2004) , (b) Virtual New York (planet9.com, 2004), (c) Virtual Zurich, Switzerland (cybercity.tv, 2004), (d) Virtual Tokyo (planet9.com, 2004), (d) Virtual Bologna, Italy (NUME project)
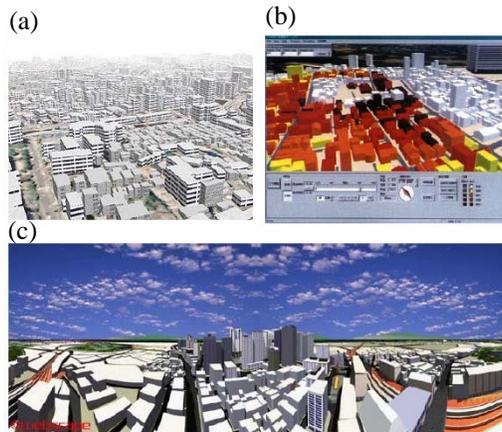

Figure 3. Virtual City of Tokyo with three different applications: (a) The Asian Air Survey Model, (b) Zenrin's Fire Spread Model, and (c) Webscape's Digital Panoramic Visualization (Batty *et al.*, 2000)
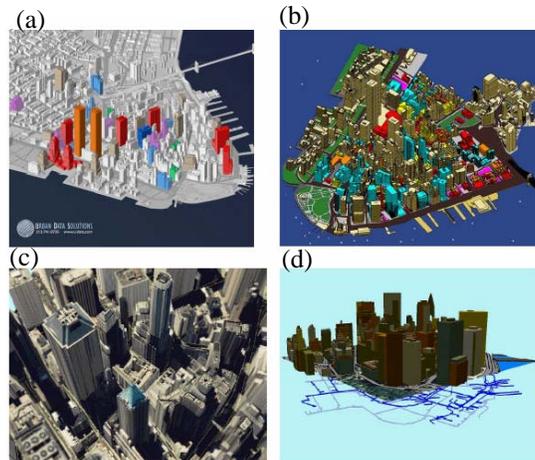
Figure 4. Virtual City of New York; (a) Urban Data Solutions – Floorspace in Downtown Manhattan (b) The Environmental Simulation Center- Floorspace again (c) ASI – Draping Orthophotos on 3d Block Models and (d) ASI –Utility Lines beneath the Floorspace Blocks (Batty *et al*., 2000).

3. Developing a Virtual 3D city model

All of the above examples give our research team motivation to develop our own 3D city model. At the beginning, minor part of Shah Alam city (Section 14, Section 11 and Section 10) as in Figure 5) has been chosen as a subject for the prototype. The reason why this area was chosen is because of its well known identity and located at the heart of Shah Alam city. We call this 3D city model as Shah Alam Virtual City (SAVC).
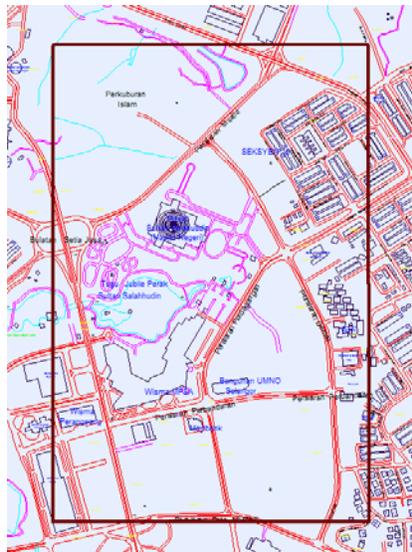

Figure 5. A topographic map of our project area

In order to develop the 3D city model, several techniques and requirement of constructing SAVC are outline below:

     i) Data source
    ii) Software and hardware
   iii) Modeling approach
   iv) Visualization

3.1 Data source

The starting point of any 3D city models is the data source. The main data source is a topographic map (Figure 5) and aerial photographs. Topographic map provide geographic reference which store the positional information of terrain features such as buildings, roads, rivers, contours, land use, administrative boundaries etc. Aerial photographs provide more accurate information rather than topographic map because there is no process of generalization. A stereo pair of aerial photographs is therefore used to generate an orthophoto image. Orthophoto and topographic map are used to derive building footprints. Figure 6(a) shows more accurate building footprints compare to Figure 6(a) as a result of generalization process in topographic map. Contours and spot heights from topographic map and aerial photographs are used to generate Digital Elevation Model (DEM). A DEM is a file of rows (x) and columns (y) corresponding to pixel locations. The value assigned to each pixel is the z value, or elevation. Terrestrial photographs of every single building from multiple view point are needed to construct photorealistic 3D model of buildings. These terrestrial photographs were captured using a conventional photographic technique using digital camera.
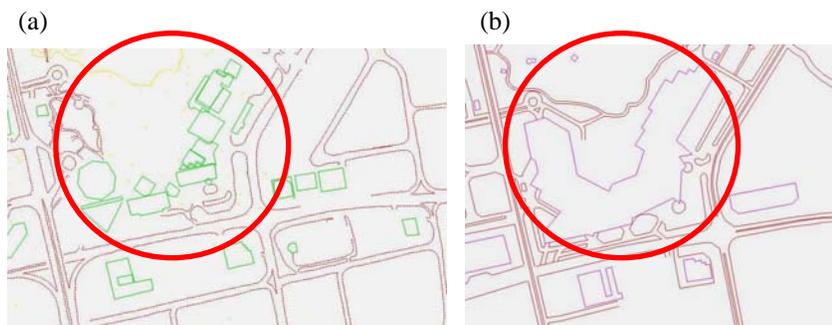

Figure 6. Building footprints derived from (a) orthophoto and (b) topographic map

3.2 Software

The software used and evaluated in the project is listed below and categorized into several different types:
  i) GIS software
      ▪ ArcGIS
      ▪ MapInfo
  ii) Image-based modeling software
      ▪ Canoma
      ▪ Realviz Image Modeler

iii) 3D/VR GIS plug-in software
- Sitebuilder (ArcGIS plug-in)
- Pavan (MapInfo plug-in)

iv) 3D modeling/authoring software
- 3D Studio Max
- VizX3D
- ModelBuilder

v) Visualization software
- Cosmo player
- Cortona
- Flux player
- OpenSceneGraph

The most used applications in this project are ArcGIS, Canoma, 3d Studio Max and Cosmo player. ArcGIS was used to develop the foundation of the SAVC while Canoma was used to construct a photorealistic building model. 3D Studio Max was used to authoring and integrating the foundation, building and other urban features (e.g. tree, lamp post and signboard).

3.3   Modeling approach

The modeling technique used in this project can be divided into several tasks and short structural summary presented by workflow scheme (Figure 7).
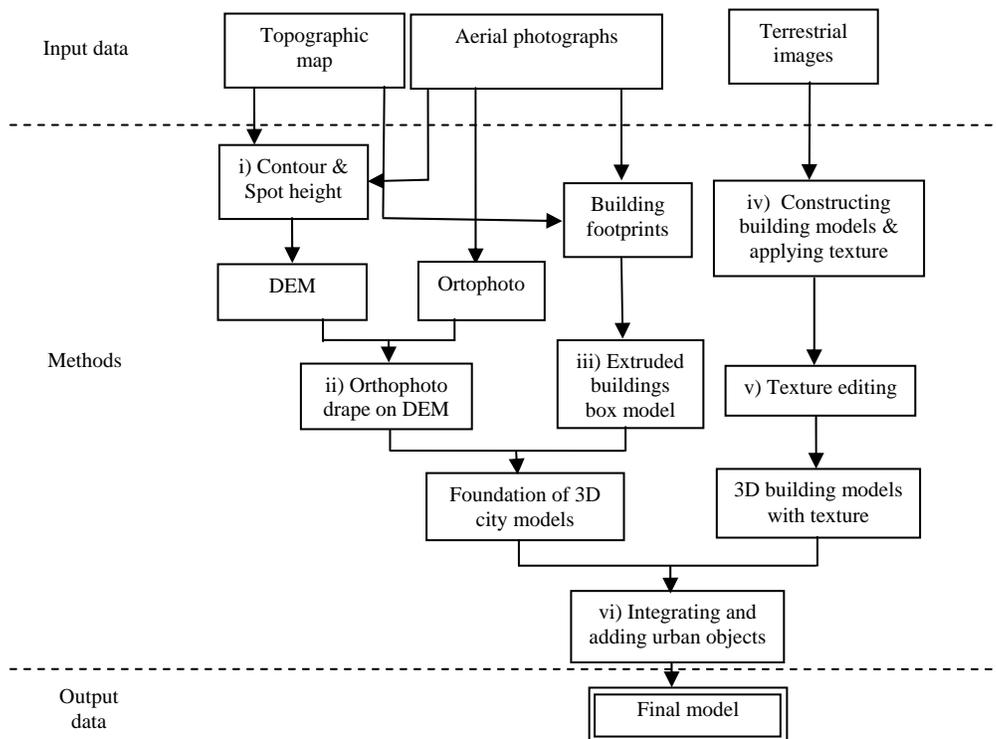
Figure 7. A workflow scheme of methods used in the project

i) Interpolation of spot height and contour from topographic map and aerial photograph to produced DEM of a study area was performed using ArcGIS software. The result is shown in Figure 8(a).

ii) The next step is superimposing or draping process, a 2D representation of topographic features, e.g. roads, rivers & land use information from orthophoto as in Figure 8(b) is superimposed or draped onto a DEM. The result is shown in Figure 8(c).
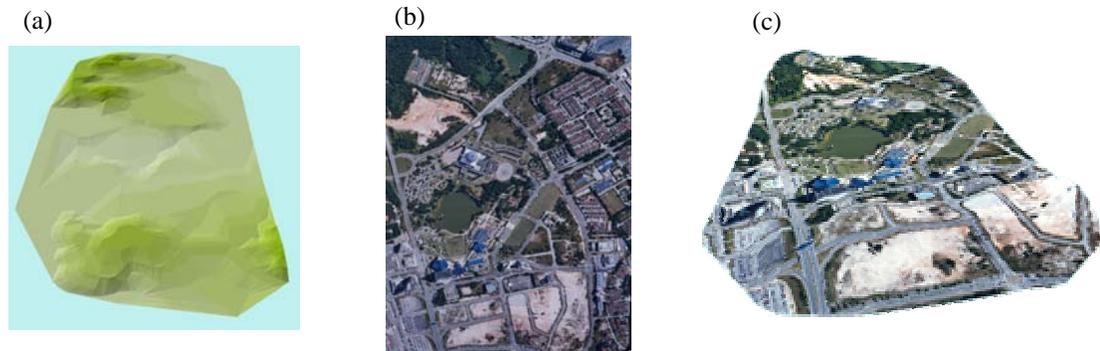

(a) (b) (c)

Figure 8. (a) DEM, (b) Orthophoto and (c) orthophoto drape onto DEM

iii) Building footprints from aerial photograph and topographic map are extruded according to height derived from digital photographic technique and then merge with orthophoto and DEM to produce the foundation or initial model of SAVC (Figure 9)

Figure 9. The foundation or initial model of SAVC

iv) In other development, multiple view point of terrestrial images is used to reconstruct photo-textured building models. This is the most painstaking parts. The building models created using simple primitives of Constructive Solid Geometry (CSG) such as a box, roof, rectangle and pyramid. Then the CSG (in wire-frame) is pinned to images to create a building model (Figure 10). Figure 10 shows the constructing and texturing process of single complex building while Figure 11 shows the constructing and texturing process of multiple buildings.
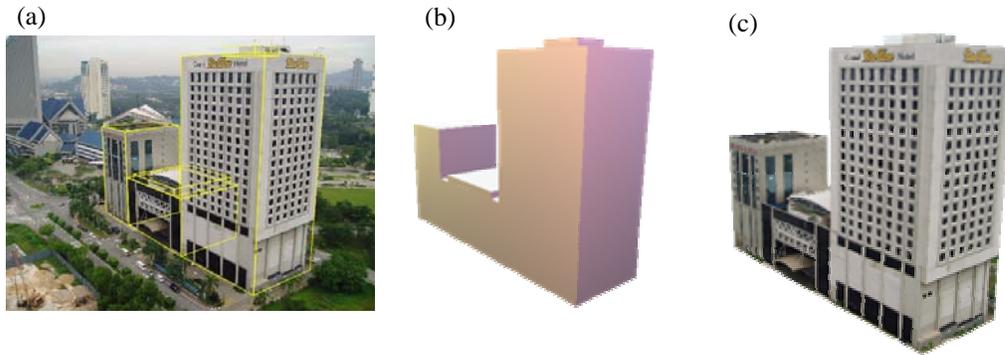
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Figure 10. Reconstructing the Grand Bluewave Hotel (a) Image and wireframe view (b) 3D model view (c) 3D building model with texture view
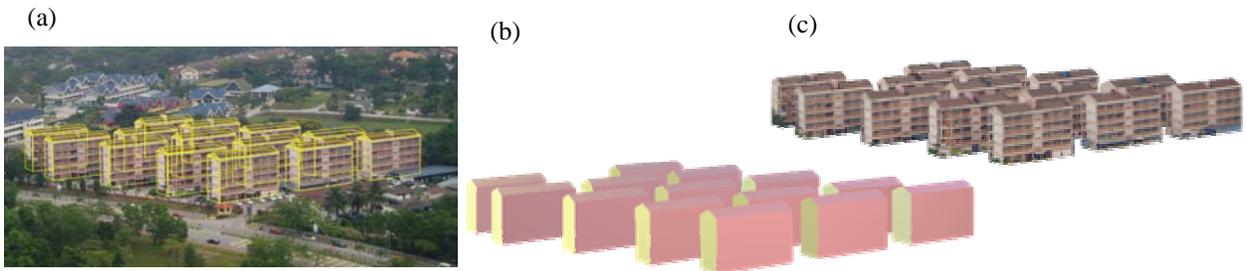

Figure 11. Reconstructing the Police Quarters (a) Image and wireframe view (b) 3D model view (c) 3D building model with texture view

v) Editing the texture of building model is to eliminate the shadow effect and obstructing objects like tree and vehicle. The process is carrying out using image editing software like Adobe Photoshop. Figure 12 shows two building texture before (a) and after (b) editing process.
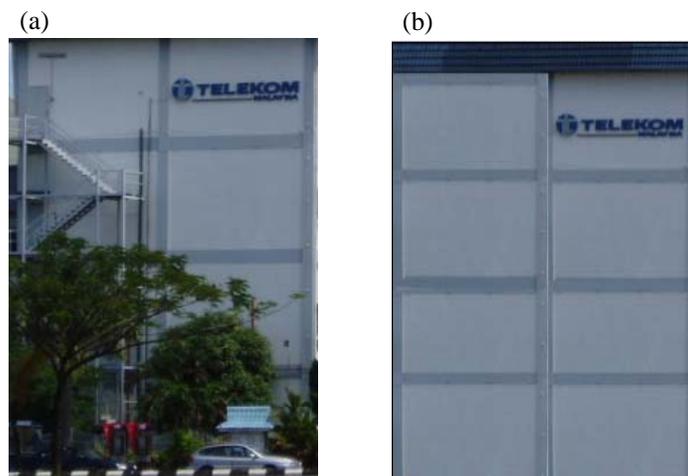

Figure 12. Editing texture of Telekom building (a) before and (b) after effect

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vi) The final process in developing SAVC is to integrate both foundation of the initial city model with the photorealistic building models and adding-on extra accessories (landscape objects) such as trees, lamp post, sign board, bus stop etc. This process is completed using 3D modeling/authoring software (e.g. 3D Studio Max) and the result is shown in Figure 13.
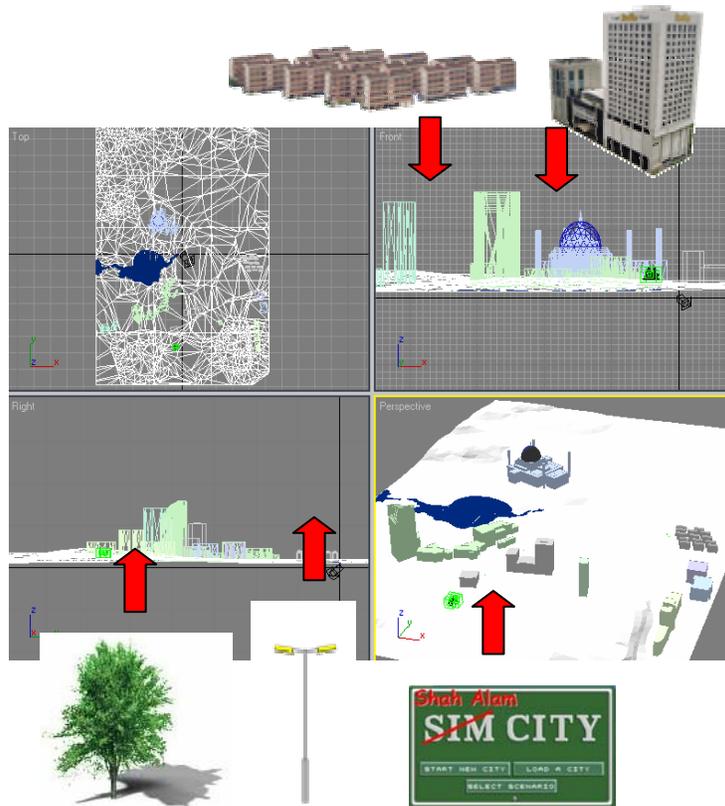

Figure 13. The final process of modeling in 3D software

3.4   Visualization

In order to achieve the highest form of visualization, VR technology is used. The refinement process of the virtual 3D city model is done in Virtual Reality Markup Language (VRML) and X3D format. VRML is the ISO standard to display 3D data in the web. X3D is an Open Standards XML-enabled 3D file format to enable real-time communication of 3D data across all applications and network applications (web3D.org, 2004). X3D is the next revision of VRML, it provides greater flexibility and resolved several issues in VRML. Using the VR technology, we can immerse into the virtual environment and navigate through the model by walking, flying and examining. This can be done by exporting the model into VRML or X3D format and using software plug-in like Cosmo player (VRML) or Flux (X3D) as in Figure 14.
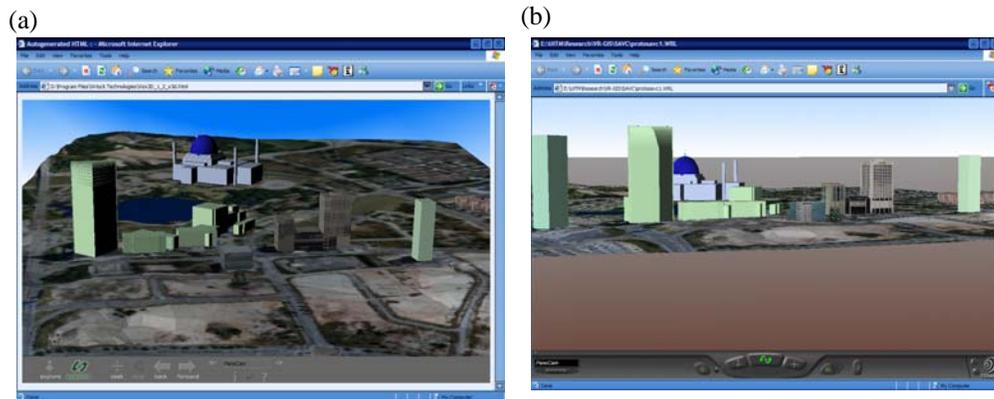
Figure 14. Visualizing the SAVC in virtual environment using (a) flux and (b) cosmo player

4. Application – visual analysis

Visual analysis is an important component of landscape planning and parts of a process which would identify the most suitable site for a development of a project (IEATLI, 1995). DEM, topographic, and orthophoto images were overlaid in 3D city model to interpret the aesthetic aspect of the study area. A general impression of landscape sensitivity to development and acceptability of alternative development layout can be seen.

Projective view provided in Figure 14 reveals the extent of visibility of the development to its surroundings, and to what extent the development is visible from its surroundings. DEM, topographic layers, and orthophoto image were overlaid in the 3D city model which enables the interpretation of aesthetic impact.

Figure 14. Projective view of the 3D city model

This product allows users to interpret the land-base features for themselves. The clarity and detail visible on the map depends upon the scale of the map and the resolution of an image used as a backdrop. High-resolution images provide more complete, accurate, and comprehensive information than traditional vector based maps. Further analyses on visual aspects are restricted by the modeling capability available for this study, for example, to generate massive amount of photo-textured 3D building models.

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A general impression of landscape sensitivity to building construction and acceptability of alternative development layout can be seen in Figures 15(a) and 15(b). Projects, for which locations are not yet finalized, may have results an analyst to select the most suitable site, since this model can portray the magnitude of impacts in order to ascertain the public perception (Figure 16).
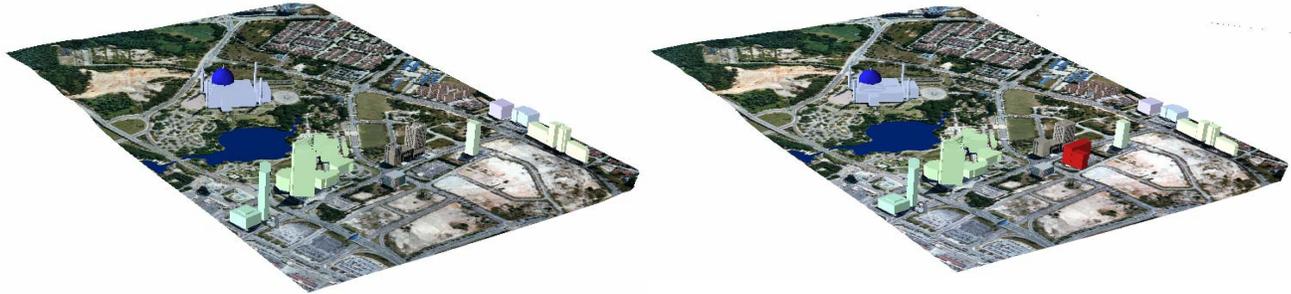

Figure 15. (a) Perspective view without new project (b) Perspective view with proposed building (in red)

Figure 16. More closer look to the proposed building

5. Conclusion

Virtual 3D city models are improving the practice of urban environmental planning and design. The visual display capabilities illustrated in this project enable the explanation of the development plans or alternatives to the public. Public interest and understanding can be raised by using both graphic and image files that show the relationship between the proposed project and individual properties, neighborhoods, local landmarks, community services, and other features. If a picture worth a thousand words, virtual 3D city model is worth a thousand pictures.

Further analyses on visual aspects are restricted by the data source available to this study, for example, to manage large 3D urban databases as well as the automatic database generation. In order to produce good quality and readable output, proper hardware, software and design criteria are required.

Construction of 3D building model has been active research topic in recent years. Most approaches have been focused on the reconstruction of specific building models: rectilinear shapes and flat roofs. The automation of extraction of buildings from various data sources is a

very desirable and challenging yet equally difficult task because of the great number of possible building forms and shapes.

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