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USING 3D GIS SIMULATION FOR URBAN DESIGN

Abstract

The Florida town of High Springs joins the University of Florida to develop a vision for the revitalization of its historic town center. An essential component of this effort is the ability to communicate to the citizens of High Springs the present physical and socio-economic conditions and be able to interactively visualize the proposed design alternatives. To achieve this objective the design team uses 3D GIS to simulate a number of 'before and after' scenarios. This paper discusses several key elements for the development of the 3D database and the real-time 3D visual simulation as well as the ability to interactively query and display the associated GIS information using ArcGlobe. It also provides a methodology for developing 3D urban photo-realistic symbology for ArcGIS using a combination of 3D modeling and soft photogrammetry software. The paper addresses issues relative to advantages of interactive real-time visualization and current limitations of this technology for urban planning and urban design.

1. INTRODUCTION

Urban design is concerned with shaping the physical environment of cities. To address the complexity of form and function of cities, considerable information needs to be processed and exchanged between design professionals, the public and the decision makers. In this process, communicating proposed ideas to political decision-makers or the wider public is a key activity for success (Batty et al., 2000). Since urban design deals with the physical environment, its solutions are presented as a combination of visual and descriptive information that show how to change the shape of our cities. Such information includes two-dimensional (2D) plans, maps and drawings, as well as three-dimensional (3D) drawings and models of proposed interventions. The presentation of such information, due to its visual nature, dictates the need for an effective way for visually communicating it to the stakeholders involved. The participants in the urban design process, especially the public, often experience difficulty understanding the complex spatial relationships of physical form when portrayed by limited presentation capabilities of the 2D traditional media. These difficulties can often lead to miscommunication between urban designers and the involved parties especially when the general public is involved in the design process.

The city of High Springs Florida was faced with such design communication problems during its town center redevelopment project. High Springs, with a population of 3,863 is a rural community located at the edge of the Gainesville metropolitan area in north central Florida. In order to generate design alternatives for the town center, the city planned a collaborative urban design process that encouraged participation of many different stakeholders such as urban design professionals, citizens, and city planners. Early in the process, the city encountered the problem of the miscommunication among the stakeholders as well as the shortage of data used for analyzing the current social and physical condition of the town center. In order to facilitate the redevelopment project, a research team of the University of Florida developed a 3D GIS simulation tool. The 3D simulation tool allowed users to interactively navigate a photo-realistic 3D urban model of the High Springs town center in real time, as well as to query and analyze attribute data associated with the GIS layers. The tool was used throughout the process to help the stakeholder understand the current condition and the proposed design alternatives in the context of the city. This paper discusses several key elements for the development of the 3D database and the real-time 3D visual simulation as well as the ability to interactively query and display the associated GIS information using ArcGlobe. The paper provides a methodology for developing 3D urban photo-realistic symbology for ArcGIS using a combination of 3D modeling and soft photogrammetry software. In addition, the paper addresses issues relative to advantages of interactive real-time visualization and current limitations of this technology for urban planning and urban design.

2. DEVELOPMENT THE 3D GIS SIMULATION TOOL

The High Springs 3D GIS simulation tool was derived from the idea of urban simulation. Urban simulation refers to

> A simulation environment that permits an end user to insert himself into a dynamic, visual model of an urban environment by means of a visual simulation system employing on-line generation of color projections onto large screens with as much as 360 degrees of vision. By means of controls which direct his speed and the direction, as well as the movement of this eye, the viewer will be able to 'walk', 'drive' or 'fly' through sequences of existing, modified, or totally new urban environments (Kamnitzer, 1972, p.315).

The High Springs 3D GIS simulation tool provides such features. In addition the simulation tool provides data query capabilities. The tool allows the user to query and analyze attribute data as is typically done in 2D GIS while navigating a photo-realistic 3D simulation scene in real-time.

The simulation tool contains datasets covering the High Springs town center area of roughly 55 acres. The database includes an accurate representation of streets, sidewalks, buildings and vegetation. The database has two major components, the photo-realistic 3D urban model and the GIS data layers. The simulation tool combines GIS datasets and the 3D urban model, ESRI's ArcGlobe, a real-time visualization simulation viewer (figure 1).

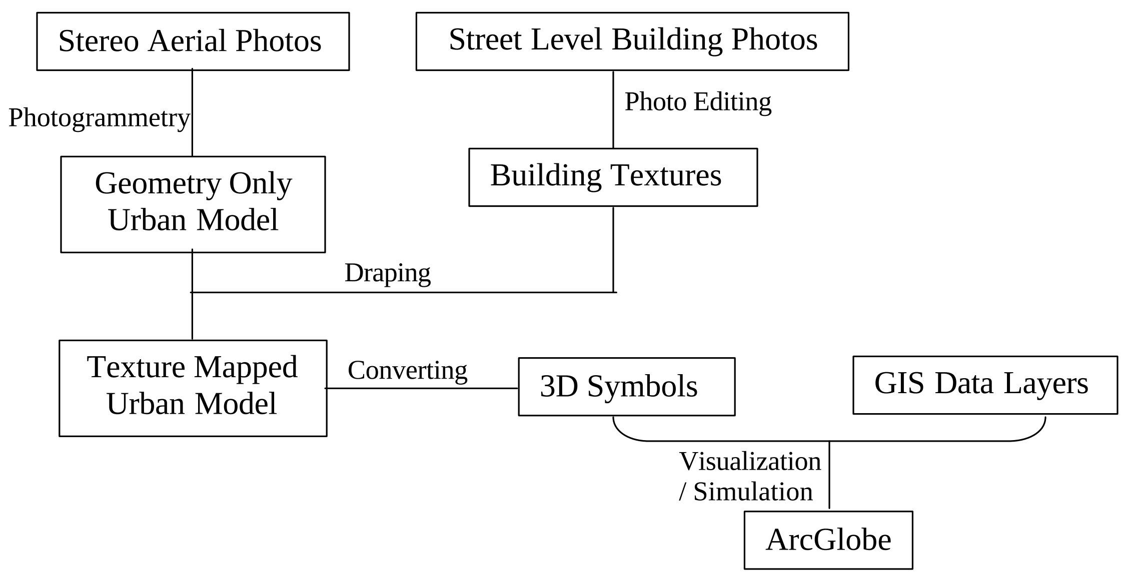

Figure 1. High Springs simulation tool development diagram

2.1 3D Urban Modeling

The physical structures of The High Springs town center were constructed in 3D using a total of 118 objects. The 3D modeling process can be categorized into three distinct procedures, geometry modeling, texture mapping, and data conversion.

2.1.1 Geometry Modeling

Digital photogrammetry technology was used to build 3D geometries of buildings. Using photogrammetry it is possible to mathematically create a 3D model of any number of features visible on two aerial photos forming a stereoscopic pair (Limp and Cothren, 2003). In order to capture 3D geometries, photogrammetry requires a stereo pair of digital aerial photographs. The software used for this project, Nverse Photo, needs to know the field of view and film dimensions of the camera and a few reference points of geometry visible on both images. Using this information the software extracts 3D geometries and elevation of objects from the stereo images.

Construction of the 3D geometry starts with modeling of the ground surface. The ground surface can be simply constructed using ground points on both images. The ground elevation is used to place the footprints of buildings. Buildings are constructed by manually digitizing the 2D polygonal shape of the roof base on only one image. The software generates a copy of the digitized shape on the corresponding image and automatically extrudes the 2D shape to the ground surface to create the 3D volume (Figure 2). The construction of complex architectural volumes and roof morphology is facilitated by the use of primitive geometric functions and associated attributes and parameters that can automatically produce a variety of shapes and volumes such as pitched roof, overhang, awning, and fencing in a relatively short period of time. For example, by digitizing the base and the ridge line of a pitched roof the software generates automatically the roof volume with the sloped planes. Trees present a major obstacle to geometry modeling using digital photogrammetry. In many cases tree canopies hide the roofs of buildings especially in densely vegetated residential areas. In such cases, decisions have to be made upon judgment based on observations, a building’s architectural characteristics, photographs and other available sources.

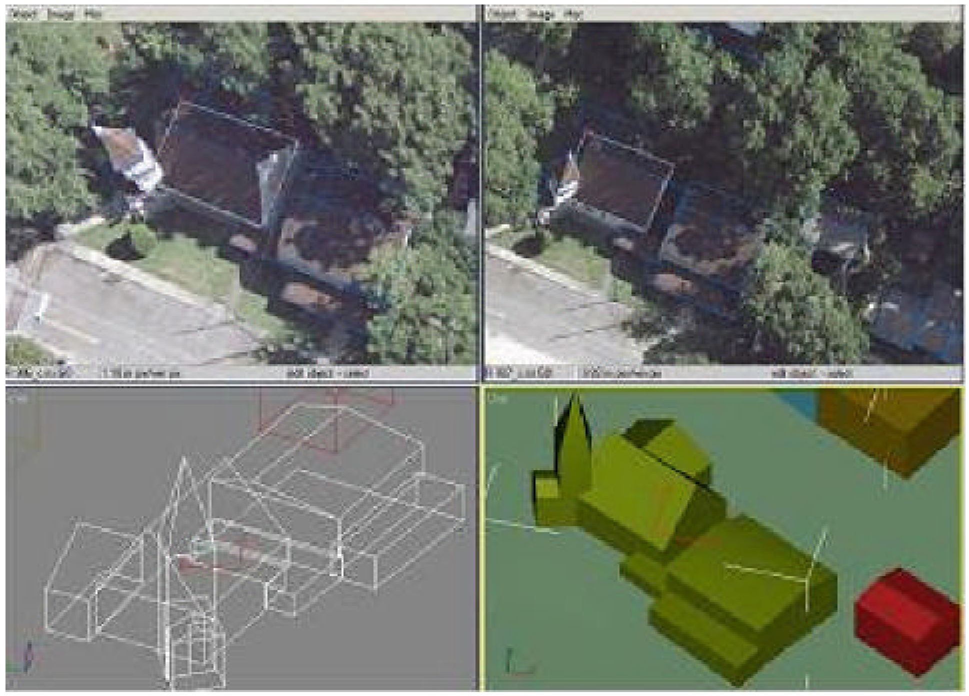

Figure 2. Geometry modeling

Although the modeling method described here works well for the majority of buildings, limitations occur when buildings contain spaces within the external mass. In this case, automatic extrusion down from the top of the building to the ground plane fails to capture the volumetric character of the building. For this reason, manual editing of the geometry was performed utilizing photos of the building at street level. Figure 3 presents an example of building geometries before and after manual geometry correction.

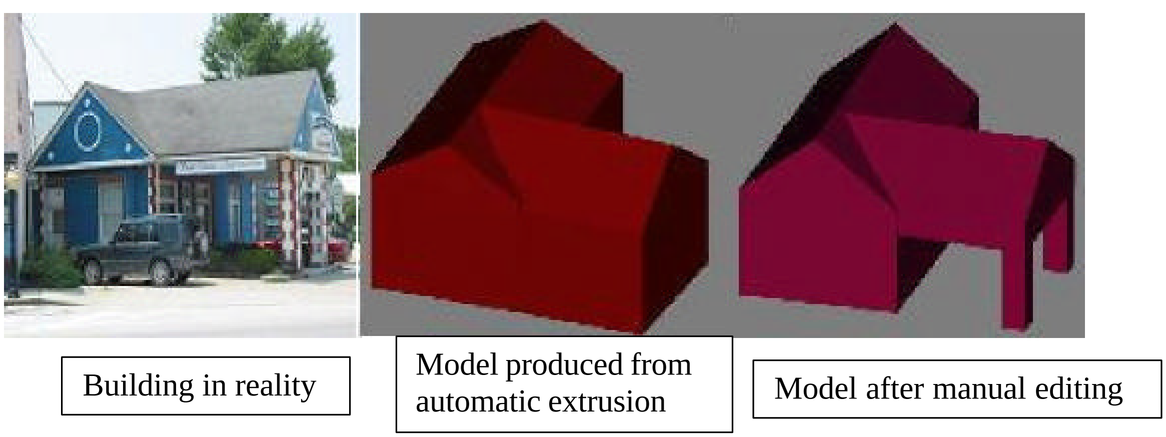

Figure 3. Modification of building geometry

2.1.2 Texture mapping

Urban models can be greatly enhanced by using texture mapping. Texture mapping refers to the technique that drapes and scales digital images on the surfaces of the computer-generated geometries. This technique reduces the need for detailed geometric modeling and significantly increases the level of realism of the 3D model by displaying visual information associated with buildings such as color, texture, and material. For this reason, the realism of the model was improved with higher quality façade textures (Figure 4). This was achieved by draping street-level photographs onto the building geometries. Before application to the geometry, façade photographs need to be edited in order to remove perspective distortion and obstructing objects such as trees, people or automobiles. This is typically performed manually using a photo editing software such as Photoshop. Photo editing is the most time consuming process in building a photorealistic 3D urban model. For the High Springs 3D urban model, approximately 450 street level photos were taken to capture building façade images. About 200 of those photos are used and processed to generate texture images. Throughout the photo editing process, a total of 304 texture images were created.

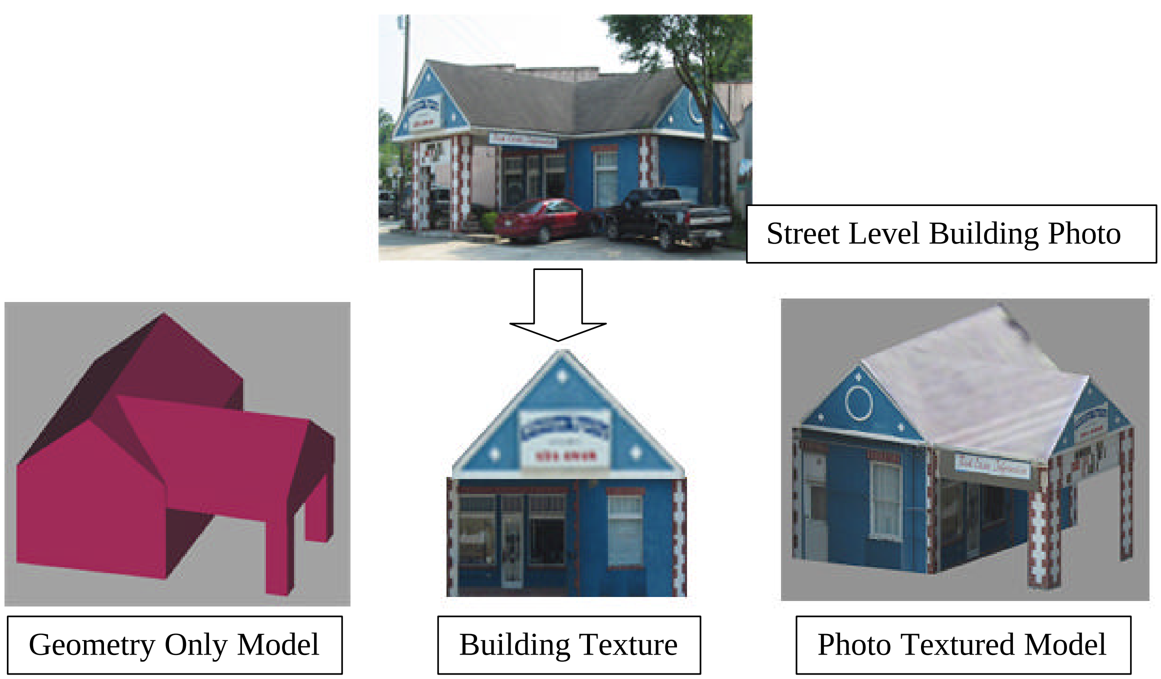

Figure 4. Texture mapping example

2.1.3 Georeferencing and Data Conversion

Georeferencing is the process of assigning geographic coordinates to spatial data. The Nverse Photo software supports georeferencing by matching several points on the aerial photography to points on the ground (called ground control points) that already have geographic coordinates. The ground control points can be collected from an orthophotograph georeferenced GIS data layers. Based on displacement of the points, the software determines the coordinate transformation method and applies it to all the objects of the 3D model.

In order to integrate 3D data to the GIS systems we treated each building model in the 3D urban model as a 3D symbol in ArcGIS. 3D symbols are 3D models (with or without textures) that are stored as individual files in a format that the GIS software can read. 3D symbols are displayed by replacing traditional simple symbols used for points, lines or polygons with symbols that are composed of 3D objects. These symbols can be used to represent a variety of GIS features such as buildings or trees or fire hydrants for point features, grass or water bodies for polygon features, and tubes for line features. ArcGIS can display 3D symbols stored as 3D objects in formats such as 3DS (3D Studio), FLT (OpenFlight) and VRML (Virtual Reality Modeling Language). In contrast to multi-patch structure, 3D symbols can display image textures. For this reason 3D symbols can be used when photorealistic visualization is required. For the High Springs project, 3D models were imported as 3D GIS symbols in FLT format. This format is designed for realtime visualization, which is available through one of the 3D GIS viewers. To produce 3D GIS symbols in FLT, each individual 3D building was saved as a MAX file since Nverse Photo operates inside Autodesk VIZ, a version of 3D Max specialized for Architecture, Engineering and Construction. Next, Polytrans, a data conversion software package was used to convert the MAX files to FLT. The 3D models of the buildings were converted independently in order to produce a 3D symbol for each building.

2.2 GIS Database

Several GIS data layers were collected and created in order to help understand the physical and socio-economic conditions of the city. The list of required GIS data layers was developed through interviews of the project site design team, the city planning advisor, city staff, and public participants. Table 1 shows the list of datasets requested from the interviewees for the High Springs visioning process.

Category	Description by interviewees	GIS Dataset	Source
Land Use	Land use map	Land use map	City of High Springs
Socio-Economic	Taxation	Parcel map	Alachua County Property Appraisal Office
	Business Type	Building footprint	Created
	Demographics	Census Block	Florida Geographical Data Library
Environment	Trees	Tree	Created
	Elevation Change	Topography map / TIN	Florida Geographical Data Library
Transportation	Road	Street network	GDT Street Network
	Traffic amount	Average daily traffic	TCI by Florida Department of Transportation
Physical Condition	Building condition	Building footprint	Created
Cultural	Historic Building	Historic Structure	Created
Other	Aerial Image	Orthophoto	City of High Springs

Table 1. List of GIS data layers

The data layers were collected from several GIS data sources. For demographic information, the census block layer was collected from the Florida Geographic Data Library, a state wide GIS and imagery GIS database for the state of Florida. Tax information for the properties in the area was collected from the Alachua County property appraisal office. The street network was obtained from Geographic Data Technologies (GDT) and from the Florida Department of Transportation (FDOT). The average daily traffic data was extracted from FDOT's Transportation Characteristics Information (TCI) and this was then joined to the street network.

Several datasets were not available and had to be created. Such data included location, types, physical conditions, number of stories and square footage for businesses in the High Springs town center. A database of historic structures was created using resources from the historic preservation records by the Growth Management Department of Alachua County and the National Register of Historic Places Evaluation Sheet by

United States Department of the Interior. A database of tree location was also collected. The design team requested location, type, height, and canopy size of trees in the project area. Due to the research team's limited resources, this database was constructed by digitizing tree location using high resolution aerial photography. The trees were categorized into three categories based on height: tall, medium, and short. Although this method was not as accurate as a field survey, it allowed relatively good quality data in a short time using limited resources. To respond to the design team's need for including trees in the visualization environment, the trees were displayed using photo realistic 3D tree symbols. The photo realistic visualization provided a close resemblance of virtual trees to their real world counterparts. The GIS data layers and the 3D urban model were integrated into an ArcGlobe simulation environment.

3. VISUAL SIMULATION USING ARCGLOBE

ArcGlobe was chosen for this project due to its capability to interactively visualize 3D photorealistic models as well as query and analyze the GIS data. ArcGlobe allows users to view and analyze very large amounts of seamless 3D GIS data at fast display speeds. Users can view a simulation scene from any perspective while flying by, walking or driving through, as well as displaying or hiding 3D objects while navigating the simulation scene. ArcGlobe is capable of utilizing GIS layers for querying 3D objects in similar fashion as 2D GIS. Figure 5 shows several screen captrures that illustrate the simulation environment of High Springs in ArcGlobe.

The performance of the simulation viewer is strongly interrelated with computer hardware capacity and the amount of data loaded into the simulation viewer. To simulate movement, the viewer should generate 30 consecutive static scenes per second. This process requires high computer resources including extensive RAM, fast CPU processing speed and above all a good graphic card equipped with fast graphic accelerators. For this project, a 2 GHz Pentium 4 with a 1 GB RAM and a mid range graphic card was used. The other factor that affects the simulation performance is the volume of data. The large amount of data required for this project (77.6MB) necessitated the need to develop a second lightweight version of the model (about half the size of the original - 34MB), in order to achieve a smoother performance of the simulation viewer.

Figure 5. Simulation scenes in ArcGlobe

4. THE ROLE 3D GIS SIMULATION TOOL

The 3D GIS simulation tool has been used in many public meetings during the High Springs town center redevelopment process. Throughout the process, the simulation tool played an important role in facilitating communication and information flow among the participants. The simulation tool helped participants to analyze the current social and physical conditions of the town center, envision the future of the town center, and evaluate several design alternatives for the specific redevelopment site.

The starting point for an urban-design project is to develop an understanding of the current conditions of a project area. This requires large amounts of information that vary from population demographics of the city to the architectural characteristics of the historic buildings. The nature of this information is both visual and descriptive. The 3D simulation tool was capable of integrating both visual and non-visual data into one common environment which facilitated analysis and data management. Furthermore, the tool helped the design team to better understand the project area by providing data query and spatial analysis functionalities while offering interactive exploration of the virtual town center in 3D. Ultimately this helped the design team to quickly understand both physical and socio-economic conditions of High Springs.

The real-time visualization functionality of the 3D simulation tool facilitated discussions in the public meetings. In public meetings discussions are dynamic, topics can change frequently, and participants often raise and discuss multiple topics at the same time. To support such a complex environment, the interface and visualization capabilities of the communication tool must be dynamic and flexible. The 3D simulation tool supported real-time visualization and provided information that stakeholders requested. The capability of the tool to visualize the data in real-time was very useful for communication between the design team and the public. The tool was also effective when used for preliminary design review among urban designers.

Finally, the 3D simulation tool supported the design team's presentation of the design alternatives. The proposed design plans were converted to a GIS compatible 3D model and were inserted into the High Springs 3D model. ArcGlobe functionality that allows displaying and hiding of GIS layers helped to compare the design proposals in a 'before and after' 3D simulated environment in the context of the town center surrounding environment. This functionality improved the communication between the design team and the public a great deal. The public was quick to appreciate the superiority of the 3D interactive model of buildings and trees over the polygon and point representations in traditional 2D design plans. Figure 6 illustrates 'before and after' visualization of one of the design proposals.

Current Condition of the Project Site

Proposed Design

Figure 6. Before and after visualization of a design proposal

5. LIMITATIONS OF THE 3D URBAN SIMULATION TOOL

Despite the advantages discussed above, the simulation tools developed for High Springs presented several limitations. The first limitation related to the handling of the large amount of data and the performance of real-time simulation. On a 2 GHz CPU, 1 GB RAM and mid-range graphic card the simulation sometimes slowed down and the viewer occasionally crashed. Table 2 shows the amount of data used in the simulation environment. When the 3D model with high-resolution textures was loaded into the viewer, the simulation performance dramatically slowed down. For this reason, the 3D model with low resolution was used throughout the research process. Even with the low resolution model the simulation viewer slowed down at times, especially during the walk through simulation. Reduced performance was clearly observed by public meeting participants.

	High Resolution Model	Low Resolution Model
3D Model	76,498 KB	33,840 KB
GIS Data	152 KB	152 KB
Total	77,650 KB	33,992 KB

Table 2. Data used for simulation

A second limitation closely related to the amount of data used in simulation is the time required to load and unload a simulation scene. It takes several minutes to load the photorealistic 3D model into ArcGlobe. This makes loading and unloading the simulation scene during the discussions impractical and inappropriate. The time requirement to load the data delayed or suspended communication and information flows and as a consequence the participants in the public meeting were easily distracted especially those meetings that were attended by a large number of participants.

A limited 3D symbology classification capability is another limitation of the simulation tool. The simulation viewer can handle 3D photorealistic objects as 3D symbols. The 3D symbol is a graphical representation of an object. The simulation viewer assigns each 3D building object to each feature based on each feature's ID. No data classification methods are supported.

The fourth limitation of the simulation tool is related to the representation of the terrain. Showing elevation changes of terrain is an important feature for urban design and 3D simulation. Typically terrain is represented by a data type known as Triangulated Irregular Network (TIN) model for terrain visualization. TIN is a vector data structure that partitions geographic space into contiguous, non-overlapping triangles. At present ArcGlobe does not support TIN data. As a consequence, the simulation tool cannot visualize the elevation and slope changes of land which present a severe limitation of the simulation tool in sloped terrain areas.

Another drawback of the simulation tool are the limited labeling capabilities of 3D objects. Labels enhance a 3D model with descriptive information. For example, a label may describe the type of a new proposed building. The simulation tool used for this research does not support 3D labels.

Last, the simulation tool has limited 3D modeling options. The simulation tool can move, rotate, and scale the objects in a simulation scene, but is incapable of manipulating a 3D object's geometry. It was observed that after design professionals and public participants became familiarized with the simulation process, more advanced simulation options are needed. For example, a very commonly requested feature is the ability to make changes to the geometry or the textures of the proposed buildings and visualize the changes interactively. However, at present the simulation tool falls short of 3D modeling capabilities.

6. CONCLUSION

The High Springs 3D GIS simulation tool combines a photo realistic 3D urban model with a variety of GIS data layers. It visualizes the 3D model in an interactive real-time environment. In addition, the tool provides data query and analysis functionalities similar to 2D GIS. Due to such functionalities, the 3D simulation tool improved the collaboration of the participants in the High Springs town center redevelopment project. The simulation tool facilitated data analysis of the social and physical conditions of the town center and supported the evaluation of the proposed design alternatives for the project site. Using this simulation tool, the design team achieved better understanding of the site conditions and its relationship to the surroundings and helped public participants minimize the difficulties of understanding and comparing the new design alternatives. The most problematic issue in using the 3D GIS simulation tool was the reduced performance when using 3D photorealistic urban models displayed as 3D symbols. ArcGlobe exhibited slow navigation, long data loading time, and slow scene refresh time when handling large amounts of data. It is expected that powerful affordable graphic cards will contribute to the ability to overcome these current performance limitations. This will make 3D GIS simulation the tool of choice for urban design.

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