DEVELOPING GEOSPATIAL LITERACY THROUGH EXPERIENTIAL LEARNING: A CLOSE-RANGE PHOTOGRAMMETRY MODULE

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ABSTRACT

Many scholars, professionals, and students have begun to employ geospatial analysis in their research; however, the teaching of geospatial thinking, especially beyond the discipline of geography, is still in its formative stages. Geospatial thinking, a synthesis of spatial concepts, methods, technologies, and applications, is an essential and integral part of the social sciences. Studies show that today's students require teaching strategies dedicated to experiential learning that facilitate knowledge acquisition by making use of their unique development skills, heavily grounded in visualization and spatial perception. This paper focuses on the unique role geospatial technologies such as Geographic Information Systems (GIS), Global Positioning Systems (GPS), and Remote Sensing can play in the development and enrichment of geospatial understanding. These technologies serve as teaching tools to develop innovative educational approaches and applications to promote spatial literacy, providing skills and knowledge that are essential to decision-making, problem solving, and successful academic and professional careers. We propose to develop several modules that introduce students and professionals to spatial reasoning while simultaneously serving as a data collection and analytical tool. We will present a pilot module on cost-effective and time-efficient close-range photogrammetry that focuses on, but is not limited to, the discipline on anthropology. This module uses experiential learning to facilitate student-oriented learning by integrating theory with practice.

INTRODUCTION

In recent years, the use of geospatial technologies has become widespread in many professions; however, the teaching of geospatial thinking in academia is still in its formative stages. Given that natural and cultural phenomena take place in space, we contend that geospatial thinking, a synthesis of spatial concepts, methods, technologies, and applications, must be an essential and integral part of social science education (Burrough and McDonnell 1999; Goodchild and Janelle 2004; Hayden 1995; Kwan and Lee 2004). The nature of spatial thinking necessitates hands-on, experiential learning that allows students to acquire and apply problem-solving skills and analyze relationships at different scales and across disciplines. Geospatial technologies such as Geographic Information Systems (GIS), Global Positioning Systems (GPS), and Remote Sensing provide tools that facilitate experiential learning, ultimately enriching geospatial understanding among students.

Researchers and educators have begun to highlight the significant impact television, virtual display, video games, and other computer-simulated environments have made on the younger generation, including those attending universities and colleges throughout the United States. Studies show that today's students require innovative educational strategies that encourage knowledge acquisition by making use of contemporary development skills, heavily grounded in visualization and spatial perception. Spatial literacy is critical; however, learning materials and teaching strategies utilizing traditional lecture-based formats often forgo other more creative strategies that are better suited to teach geospatial thinking such as scientific visualization, which offers a more creative approach to facilitate learning through visual representations of complex data and spatial relationships (Edelson and Gordin 1997; Silverman 2003).

We believe that close-range photogrammetry, a non-invasive, technique to acquire data from photographs, offers a means to introduce students to geospatial technologies and develop spatial thinking. In this paper, we present a pilot module that introduces students to the concept of close-range photogrammetry by allowing students to create a 3D computer-simulated model of an archaeological artifact. Such an approach utilizes experiential learning, integrating theory with practice and promoting spatial literacy. In general, this classroom module serves two objectives 1) introduce students to close-range remote sensing technologies and 2) facilitate the development of spatial literacy among students. It is part of a larger effort to promote the use of GeoScience and geospatial technologies in order to enrich student learning (Lock 2003; van der Elst et al. 2006; http://www.csiss.org/SPACE/).

CULTURAL BACKGROUND

The archaeological site of Copan, the largest Ancient Maya center in the southeast periphery of the Maya lowlands, is located in the Copan Valley of Honduras about 14 km east of Guatemala (Figure 1). Its main architectural complex, the Principal Group (Figure 2), was the setting for many regime-organized ritual and political acts that served to legitimize and reaffirm dynastic power by linking dynastic rulers to the past and to the supernatural (Fash 2001; Webster 2002). This civic-ceremonial center is comprised of monuments and ancestral temples that provide archaeological data for many interpretations about Copan's sociopolitical and ideological arenas. Altar Q, located in Copan's West Court, which was erected by Copan's last dynastic ruler in AD 775 about a half-century prior to the Maya 'collapse' offers an interesting artifact to carry out a close-range photogrammetry project (Figure 3).

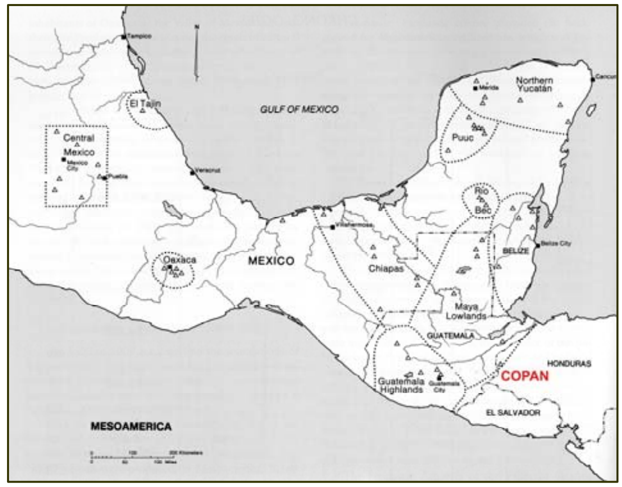


Figure 1. Archaeological Site of Copan, Honduras (adapted from Ferguson and Rohn 1990).

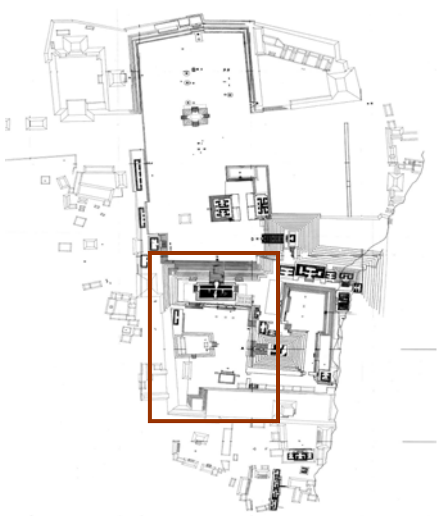


Figure 2. Principal Group at Copan. Insert illustrates West Court (Hohmann and Vogrin-Hohmann 1982).

Figure 3. Photographs of Altar Q in West Court in Principal Group, Copan (Richards 2005).

CLOSE-RANGE PHOTOGRAMMETRY MODULE

Close-range photogrammetry, a remote-sensing technique to acquire data from photographs, can be used to record and collect data on archaeological features and artifacts. These data, in turn, can be used to create 3D computer-simulated models from which measurements can be derived, mass and volume illustrated, and varying visual-spatial perspectives explored. In this module, photographs of Altar Q will be ingested into *PhotoModeler Pro 5.0*, a photogrammetric software package, to demonstrate the process of creating a simplistic 3D model of an archaeological artifact.

The process of digital photo documentation and 3D model development involves three major phases. The first involves calibrating the camera and lens. The second phase is to acquire the images, and the third is to digitally process them in a photogrammetric software package, in this case, PhotoModeler Pro 5.0.

PHASE I: CAMERA CALIBRATION

Camera Diagnostics

The camera used to acquire the digital images for this project was a Nikon Coolpix 5700 non-metric digital camera. A normal lens with a focal length ranging from 8.9-71.2 mm was used; however, a fixed focal length of 8.9 mm was used to standardize the shots and provide a relatively wide-angle setting without using a wide-angle lens. The camera has a resolution of 5.0 megapixels.

Calibration: What is it? Why is it important?

The calibration of the camera to the PhotoModeler software is necessary to remove the distortions in the images that are created by the lens. Removing the distortion has a major advantage in that it permits higher measurement accuracy in the 3D model. PhotoModeler requires all photos to maintain fixed settings for three parameters in order to use the software for 3D models. These parameters are: (1) same camera, (2) fixed focal length, and (3) standard image width (pixels) and image height (pixels). The parameters for this project are: Coolpix 5700 camera with normal lens at most-wide angle setting, Fixed focal length 8.9 mm, and Image Height 1704 (pixels) and Image Width 2560 (pixels).

For brevity's sake, the calibration for this project has already been completed. A standard camera calibration using the Calibration Grid provided by PhotoModeler was used to calibrate the Coolpix camera (Figure 4). The final calibration solved all of the internal camera parameters and produced a total error of 0.232 (Filename: *FullAutoCalibration_Plotter.pmr*). This correlates to an accuracy of approximately .23 cm. However, the actual accuracy of the final 3D model depends on the parameters and precision of marked and referenced points in the final project and not only on the calibration used for the project.

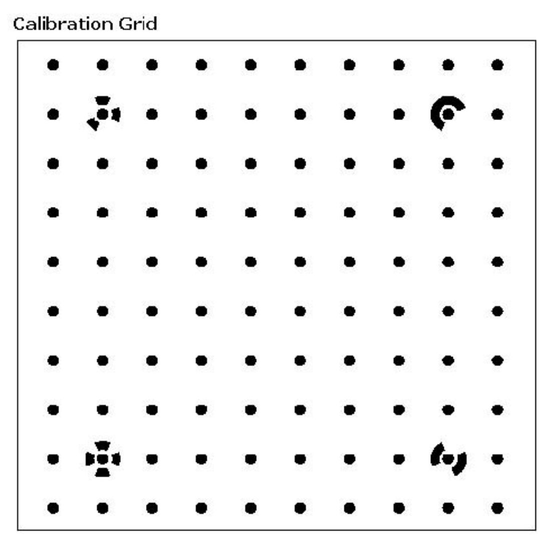


Figure 4. AutoCalibation Grid Sheet (PhotoModeler 5.0 User Manual, 2004).

PHASE II: ACQUIRING PHOTOS

Close-range photogrammetry requires multiple photos from varying angles to provide sufficient reference points and ample coverage of the artifact to be modeled, in this case a 8th century stone-carved altar from the Ancient Maya site of Copan, Honduras (Figure 5). Once the camera calibration is complete, the photos of the artifact to be modeled are taken. The higher the resolution of the digital images of the object, the higher the measurement accuracy of the model; therefore, the camera was set to obtain photos at the highest possible resolution. Each photo required 15.2 MB of storage space.

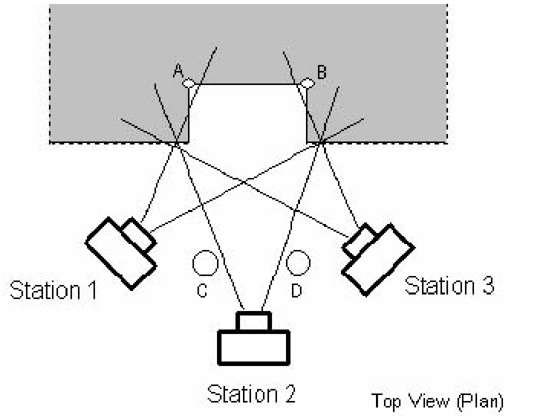


Figure 5. Ideal Camera Stations (PhotoModeler Pro 5.0 User Manual, 2004).

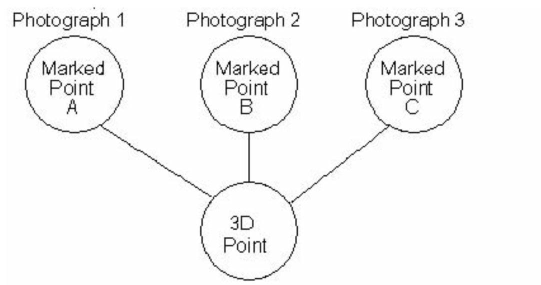


Figure 6. A 3D Point Derived from Marked Points (PhotoModeler Pro 5.0 User Manual, 2004).

Referencing Photos

Referencing is the process in which points, referring to the same physical point on an object to be measured, are marked. These referenced marks are used to create a 3D point (a point with a location in space) for which x, y, z coordinates are solved and used to generate the 3D model (Figure 6). Referencing requires that points be marked on a reference photo, i.e. the photo to which other photos will be referenced, and then on subsequent destination photos. A marked point with the same location must be marked on at least two photos in order to generate a 3D point; however, three is ideal. Therefore, it is essential to remember that when taking photographs of an object, a common point should be visible in at least three photos. Moreover, these photographs must be taken at approximately 45 angles relative to one another. We will refer to referencing later in the module as we mark and reference points.

PHASE III: 3D MODEL DEVELOPMENT

Now that a background on camera calibration and photo acquisition has been given, the tutorial will turn to 3D model development, on which a greater part of the module focuses. After the camera has been calibrated and the digital photographs acquired, phase III begins. This phase is comprised of seven steps. They are as follows:

1. Setting the approximate project size and measurement units
2. Describing the camera parameters
3. Importing initial photograph images
4. Marking and Referencing points
5. Processing
6. Adding new photos, points, lines, surfaces, etc.
7. Doing measurements or exports

STEP 1. Navigate to the PhotoModeler Pro icon, double-click to open, and to create a New Project click on the File tab on the Main Menu. The Project Wizard will open. Choose a **Standard PhotoModeler project** and click Next. Read the steps in the Project Wizard and click Next. The Project Settings need to be entered. Select the appropriate measurement settings based on the object to be measured (e.g. kilometers, meters, centimeters, etc.) in this case Altar Q. [Hint: Altar Q dimensions are east-west 152 cm; north-south 147 cm; height 70-72cm; top 132 cm (east-west) x 126 cm.] Calculate approximate size of Altar Q, based on longest diagonal, and enter the information. Click Next.

STEP 2. The Camera Wizard opens. Given that the calibration has already been done, click the option 'A calibrated camera or a camera previously used in PhotoModeler' and click Next. Browse for the calibration file. It is stored in C:\Photogrammetry_Module*FullAutoCalibration_Plotter.pmr* and click Next. Carefully review the information in the Camera Information Dialog (Figure 7). Remember that the parameters displayed are critical to the project's success (See Calibration section). Click Next.

STEP 3. In the Photo Import Wizard, add the photographs (digital images) to the project by clicking on the Add/Remove Images button. Click on the Change Directory button, navigate to C:\Photogrammetry_Module\Images folder and select an image. All images in the folder will automatically be added to the left side of the Add/Remove Photographs dialog box. Select the photos required to carry out the project by clicking on the photos (hold the shift key to select multiple photos) and then click the double-arrow button to add selected photos to project.

There will be a total of eight photographs used in the project (Figure 8). Notice that the photos selected provide varying angles and viewpoints of the altar, which is essential to create an accurate 3D model (See Acquiring Photos). Click Next. PhotoModeler confirms that these are the images to be used in the project. Confirm and click Next. Three of the seven steps required to create a 3D model have been completed. Click the Finished button to move to Step 4.

STEP 4. Now that the calibration and photos have been added to the project it is time to mark and reference points, which is typically the most labor intensive, i.e. time consuming, phase of the project. As mentioned above, referencing is critical as it allows for the creation of 3D points.

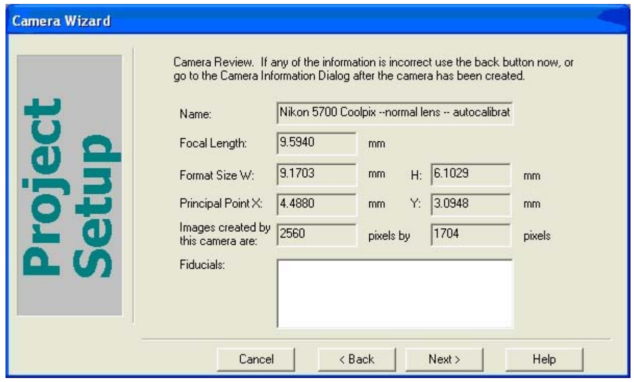


Figure 7. Camera Calibration Diagnostics.

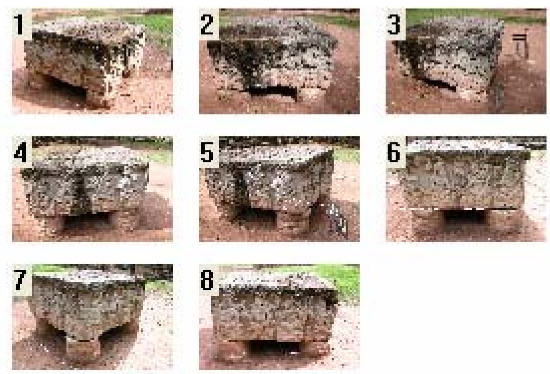
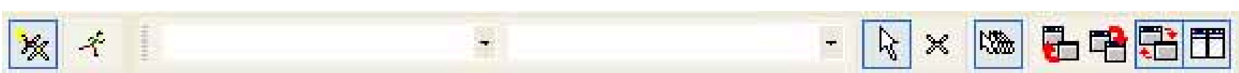


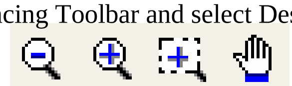
Figure 8. Altar Q Project Images.

Navigate to the *Referencing* menu and select *Reference Mode*. A new toolbar is added to the screen.



Marked points (i.e. common points among the photos) will be manually identified and used to link the images. Ideally, marked points should be visible on at least three photographs in order to achieve the highest possible accuracy. Two points may be acceptable if the photos are already well referenced, i.e. sufficiently linked to one another. However, the use of only two points is not recommended as it will most likely reduce accuracy.

The marking and referencing stage uses a *Source Photo* and a *Destination Photo*. Click on the down arrow in the left box of the newly added toolbar (Referencing Toolbar) and select Source photo 1. Now, click on the down arrow in the right box of Referencing Toolbar and select Destination photo 2 (Figure 9).

Use the zoom and pan tools  to select a common point between the two photographs.

While selecting points try to cover the full extent or visible surface of the object in order to increase the project's accuracy. That is, select at least one marked point near each corner of the object and a few throughout the interior to produce the best results.

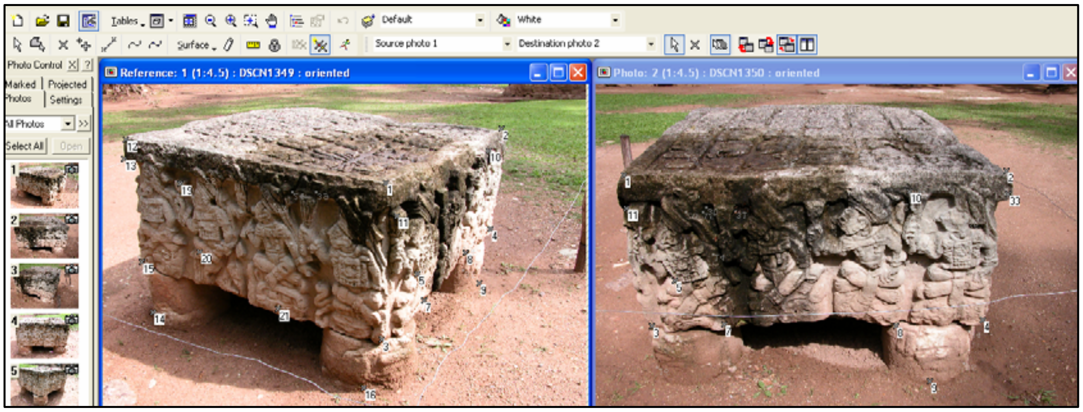


Figure 9. Marking and Referencing Points.

Now, select a second destination photo and mark the same point. Remember that to generate a 3D model from the photographs requires the same point to marked on at least 2 photos; however, three or more is optimal. Before referencing additional points, **Save Project As** *Altar Q Copan.*

Continue selecting additional marked points using Photo 1 as the source photo. Once a sufficient number of points have been selected to adequately cover the visible surface, select Photo 2 as the Source Photo, and then select Photo 3, Photo 4, and so on until all photos have been used. For brevity's sake, select approximately 35-40 reference points. Remember to select points that will give shape to the object, e.g. select points along the edges and corners of the altar.

STEP 5. After a sufficient number of points have been selected, the model will be processed. A processing dialog is used to define Camera Stations, i.e. the position of and the direction the camera is facing at the time of exposure of a photograph, and orient the photos. Click on the *Process*  button on the Referencing Toolbar.

The Processing dialog box will open (Figure 10). Click on each of the tabs to study the diagnostics of the project. In this case, the accuracy potential based on the audit details is **High**. Click on the *Process* Tab to run the project.

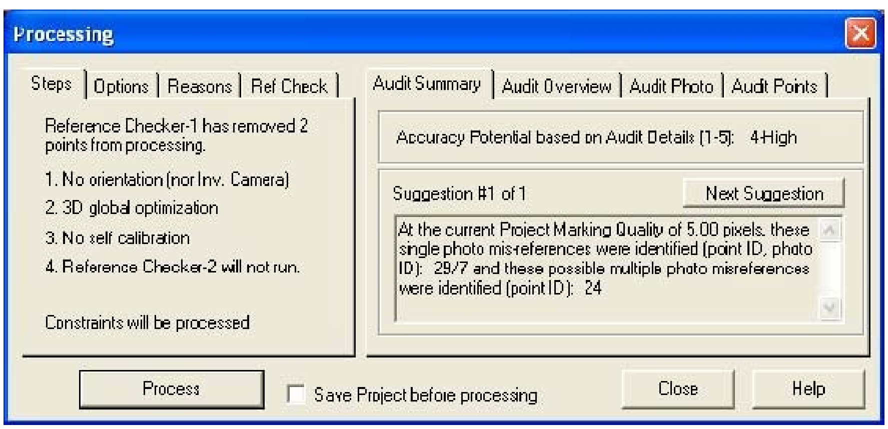


Figure 10. Processing Dialog for Referencing Marked Points.

After the project has finishing processing a *Total Error* is calculated and a *Project Status Report* is generated. Study the report. What types of errors have been introduced into the project?

The Project Status Report below indicates that a marking residual in the project is greater than 5.00 (Figure 11). A *Marking Residua*l is a residual error, or the difference between where the user marked a point and where the program expects the point to be located. The residual is critical as it represents the amount of difference between an expected and calculated value. For example, if you expected a certain measurement to come to 3.45mm, but the actual final result was 3.41mm then the residual (or residual error) would be 0.04mm.

Status Report
Project Name: Altar Q Copan.pmr

Problems and Suggestions (1)
Project Problems (1)
Problem: The largest point residual in your project (Point33 - 6.08) is greater than 5.00.
Suggestion: In normal projects, strive to get all point residuals under 5.00 pixels. If you have just a few high residual points, study them on each photo to ensure they are marked and referenced correctly. If many of your points have high residuals then make sure the camera stations are solving correctly and that your are using the best camera parameters possible.
Information from most recent processing
Last Processing Attempt: Sun Jan 29 10:08:35 2006
PhotoModeler Version: 5.2.3
Status: successful

Total Error
Number of Processing Iterations: 4
Number of Processing Stages: 2
First Error: 3.261
Last Error: 3.296

Figure 11. Project Status Report for Processing of Altar Q Copan Project.

In this case Point 33 has a marking residual greater than 5.00. Studying the residual and adjusting Point 33's position on each of the marked photographs can correct the error. Notice that the **Total Error** is 3.296. This correlates to a measurement error of 3.296 cm. Is a ~3.3 cm accuracy sufficient? Explain.

After studying the project status results, click the 'Write to text file' tab. Remember it is very important to store information about any project. The Project Status Report provides valuable data about the project.

Once all errors have been reviewed and corrected, it is time to view the project in the 3D viewer. Navigate to *Project* on the Main Menu, click on *Open a 3D Viewer***,** and select *New 3D Viewer*. In the 3D Viewer Option dialog check the boxes for Points, Point ID's, and Lines (Figure 12). Click OK. At this phase, the project is comprised only of the points that have been marked on the photos. Now, lines and surfaces will be added to the 3D model.

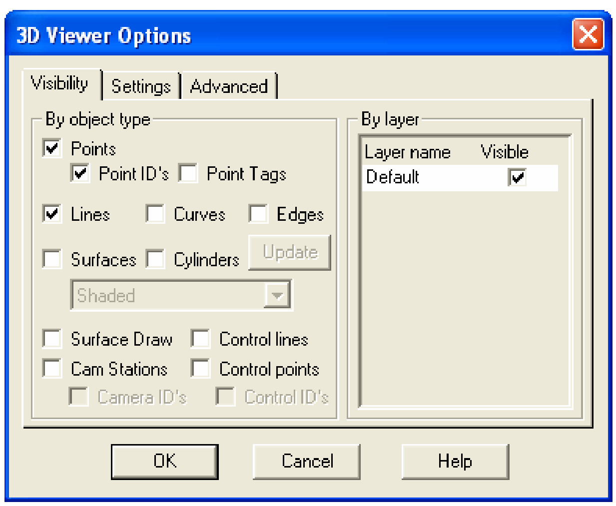


Figure 12. 3D Viewer Option Dialog Box.

STEP 6. Close the 3D Viewer and navigate to the *Marking* tab on the Main Toolbar. Select the *Mark Lines Mode* tool, which will mark lines on the project. In this case, we will mark the edges of Altar Q in order to delineate the altar's shape. Click on a referenced point using the Mark Lines tool, move to the next appropriate point and click on it to create a line. Continue this process until an outline of the altar has been generated. Open a New 3D Viewer. Uncheck the Point ID's and Click OK (Figure 13).

An outline of Altar Q has been created. To add mass to the altar, surfaces will be generated. Minimize the 3D Viewer and navigate to the *Marking* tab on the Main Toolbar, click on *Surface* in the dropdown list, and click on *Path Mode.* The Path Mode option constructs a surface using a closed loop of 3D objects such as points, lines, edges, and curves. The loop becomes the outer boundary of the surface and the interior is interpolated. *Interpolation* is key concept in many types of spatial analysis. Spatial interpolation is the process of calculating unknown values from a set of sample points with known values that are distributed across an area (ESRI Virtual Course).

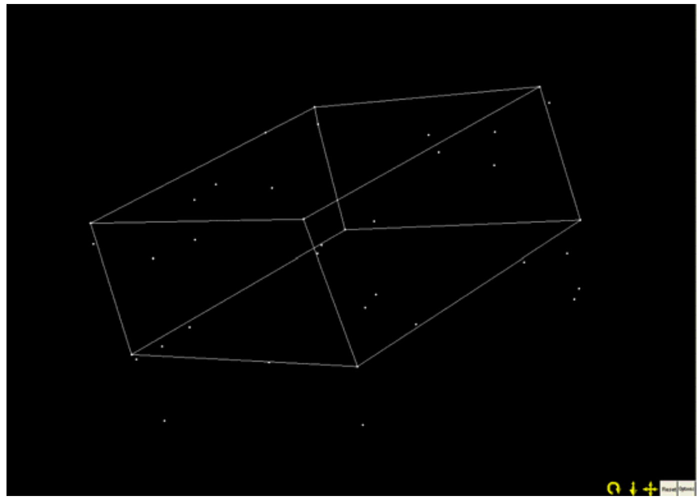


Figure 13. 3D Model of Altar Q illustrating Points and Lines.

After selecting the Path Mode tool, maximize the 3D Viewer. Click on the Options tab and check *Surfaces*. In the surfaces box, choose *Shaded*. Texture will be added later. Click OK. Given that each side of Altar Q is a rectangle, each surface will be comprised of four lines. Click on the four lines that comprise a side—they will be highlighted in red as they are selected. Remember the lines must be clicked consecutively as the Path Tool is being used. Continue creating surfaces until a box-like shaded shape has been created (Figure 14).

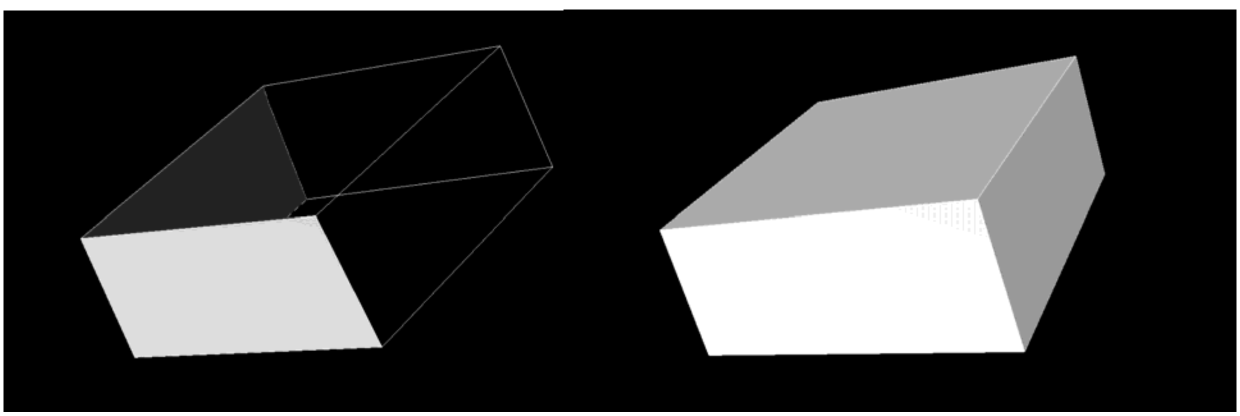


Figure 14. Surface Creation Using Shaded Option.

Now click on the Options tab to open the 3D Viewer Options dialog. In the Surfaces box, click the dropdown arrow and select Quality textures. This will overlay the Altar with the original photos used in the project (Figure 15).

Figure 15. 3D Model of Altar Q with Textured Surface.

STEP 7. We now have a 3D computer-simulated model of Altar Q; however, before the model can be used to take measurements, the 3D Scale and Rotation must be set. Scale is achieved by adding a known distance between two points in the model. Rotation uses control points or axes constraints to orient the model.

Navigate to the *Project* tab on the Main Menu and select *Scale/Rotate*. The 3D Scale and Rotation dialog box opens. Click on the *Scale* tab, select cm, type 152 in Distance box, and click on a horizontal line (e.g. red line) on the altar. Click *Define*.

Now click on the *Rotate* tab. Define the 3 parameters by selecting the appropriate lines for each required category (Figure 16). Click OK.

Open a new 3D Viewer. Click on the *Measure* tool. Click on several of the lines to study the accuracy of the measurements for the various faces of Altar Q. Click on a surface. Notice that the measurement tool automatically calculates surface area (Figure 17). The software utilizes the camera calibration information along with photogrammetric algorithms to compute distance and measurements in the photos to build the 3D model.

Play around with the 3D model. Rotate the model on its axis. Take several measurements. How do these measurements compare to those provided above for Altar Q (See STEP 1)? Given this level of accuracy, what types of questions can be addressed? Do you find the computer-simulated 3D model useful? If so, how is it useful? Does it allow you to answer questions that could not be answered using a 2D image or drawing?

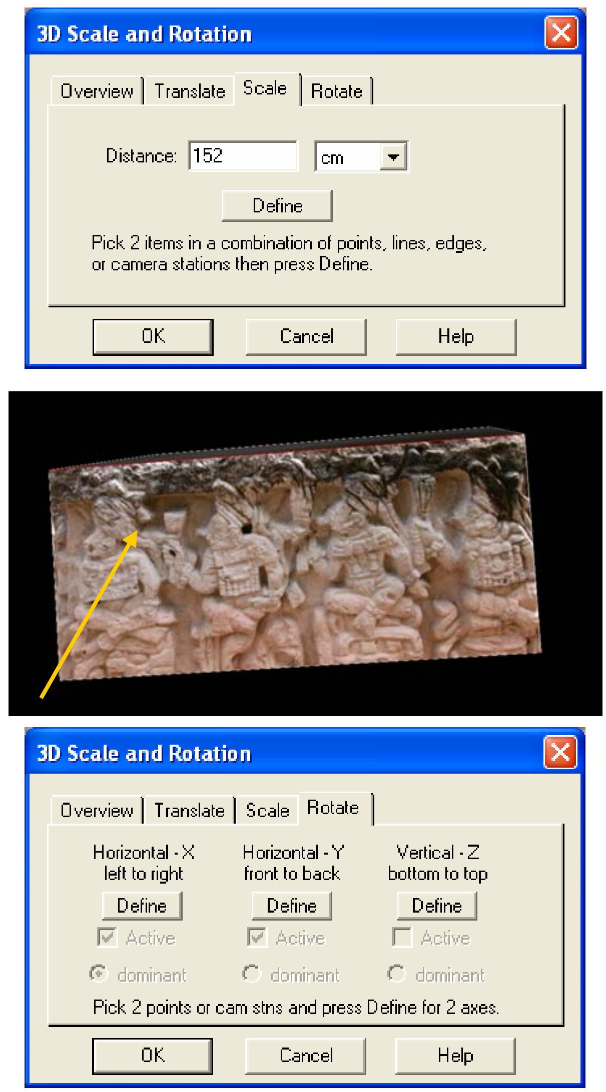


Figure 16. Setting 3D Scale and Rotation for Altar Q.

Figure 17. Using Measurement Tool in PhotoModeler.

Synopsis

Now to review the phases and steps involved in creating a 3D computer-simulated model using close-range photogrammetry. Phases I and II were done in a previous lab/field project. Phase III involved seven steps. First, the project size and measurement units were entered. Second, the camera calibration characteristics were entered into the PhotoModeler software program. Third, the photographs, or digital images, taken in the field were downloaded and imported into the software. Fourth, common points among the photographs were marked and referenced. Fifth, the images were oriented and processed to generate a virtual 3D model comprised solely of points. Sixth, lines and surfaces were added to the model to give it mass, volume, and texture. Seventh, measurements of length, width, height, and surface area were calculated.

CONCLUSIONS

This paper sets forth a close-range photogrammetry module as a means to exemplify the utility of hands-on experiential learning in developing spatial literacy among students. It provides a step-by-step guide to camera calibration, photo acquisition, and 3D model development using the principles of photogrammetry. It is our goal to develop additional modules centered on geospatial methods and analysis taking advantage of recent advances in geospatial technologies such as Geographic Information Systems (GIS) and Global Positioning Systems (GPS). We believe that spatial thinking is essential to solve many of today's scientific and social issues and thus, it is necessary to develop innovative and creative learning materials and teaching strategies that integrate geospatial perspectives in education, especially the social sciences.

The module itself fits within the broader framework of Computer Assisted Learning (CAL), which offers many advantages to traditional learning. These include: 1) computer-simulation allowing for dynamic, interactive interfaces, 2) virtual collections providing access to often restricted or unavailable objects, and 3) online modules that reach a wider audience (Lock 2003). This module, along with other modules focused on spatial learning, can be seen to complement classroom discussion on geospatial theory, methods, and applications and with further enhancement may be utilized for professional development and skill acquisition, especially in regions with limited access to skilled educators (e.g. developing countries).

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