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GEO 386G- Semester Project

Introduction

Following the economic boom which was the result of crude oil revenues the municipality of Dubai, located in the United Arab Emirates, set forward on a plan to expand it coastline and develop some luxury real estate. As part of this plan, numerous man made islands were to be constructed in several shapes. The first of these islands completed was the Palm Jumeirah, a palm tree shaped island which would contain residences, hotels and commercial buildings. The Palm Jumeirah is to be followed by the Palm Deirah, the World Map islands and the focus of my project, the Palm Jebel Ali.

Problem statement

The question to be answered using GIS is:

How much sand is required to construct one of these man-made islands?

The measurement would be volume measured in cubic meters, which are more convenient considering that the UAE uses the metric system.
After some research, the Palm Jebel Ali, although not completed, was most suitable for GIS analysis (reasoning will be explained below). The GIS analysis would involve performing a cut/fill calculation using the 3D analyst extension in ArcMap.

Data collection

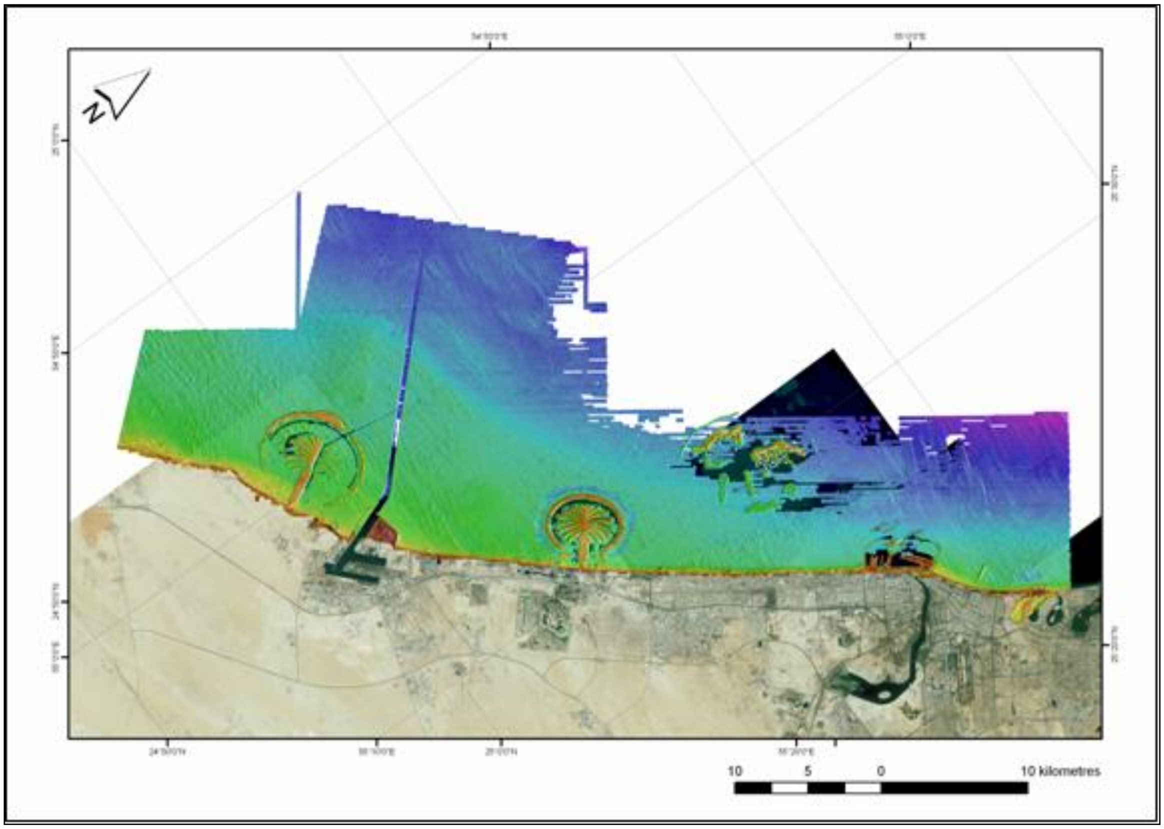
Once the problem was identified, the following list of required data was compiled:

- Satellite images of the palm islands
- Bathymetric data of Dubai coastline
- Geotechnical properties of sand
- Background information on the construction method of the islands

Acquisition of satellite images of the Palm Jebel Ali was carried out using internet search; some of the sources used were Google Earth, NASA Landsat and ESA CHRIS Proba and NASA ASTER. It was important to find an image that would have high resolution and also the least amount of shades in the photo, this would allow easier processing by GIS, to be exact, more accurate binary raster of the island. The final image used was obtained from NASA using the ASTER data, which had highest resolution and the best lighting conditions. In order to rectify these images in ArcMap point data was collected for the island using Google Earth.

Obtaining bathymetric data for the Dubai coastline was the most challenging aspect of the project; the initial internet search resulted in no sources. A broader search identified an article published by Smit et al. Titled “BATHYMETRIC LIDAR DATA GIS APPLICATIONS FOR COASTAL ZONE MANAGEMENT IN DUBAI”. The article discussed the planning and execution of a LIDAR survey off the coast of Dubai. The survey was carried out as part of the Dubai Coastal Zone Monitoring Program by the Coastal Zone and

Waterways Management Section of the Dubai Municipality. The Dubai Municipality was contacted by email in order to obtain the LIDAR survey results.



Low Resolution Results of the Dubai LIDAR survey (courtesy: Smit et al.)

As of December 2nd, no reply was made by the Dubai Municipality; in order to obtain the bathymetry of the Dubai coast, a different approach was required. The bathymetry was constructed using water depth point data given by the Google Ocean extension of Google Earth.

The geotechnical properties of sand were probably the easiest data to obtain. Basic geotechnical texts in the UT engineering library contained relevant data which was verified with graduate students in the geotechnical engineering program. Recorded data included the unit weight of undensified wet sand, the dry unit weight of sand, compaction factors for the sand, angles of repose for sand. All these figures would later be used to evaluate the accuracy of the GIS analysis and account for factors GIS did not.

The Nakheel development company, which is responsible for developing the palm islands had basic information on the construction methodology of the palm islands. The islands were constructed using sea dredged sand from the coast which was placed and then vibro-compacted. The islands are protected from surges by rock built breakwaters. “Vibro-compaction is used to densify clean, cohesionless soils (like sand). The action of the vibrator, usually accompanied by water jetting, reduces the inter-granular forces between the soil particles, allowing them to move into a denser configuration, typically achieving a relative density of 70 to 85 percent. Compaction is achieved above and below the water table.” (source: haywardbaker.com)

Data preprocessing

Once collection of raw data was complete, preprocessing could take place. First, the images downloaded from NASA were converted from JPEG format to the ArcMap friendly TIFF format, rather than RGB data the images were converted to grayscale, finally, the image resolutions were adjusted; all these operations were performed in Adobe Photoshop. The TIFF images were then rectified in ArcMap using coordinates obtained from Google Earth. The images were then projected in UTM coordinates using ArcCatalog. The geotechnical properties of sand along with the information gathered on the construction method were used to estimate the compaction factor of the sand and also to estimate the additional amount of sand required to slope the sand at its angle of repose.
Further preprocessing involved creating a point feature class in ArcCatalog in which the sea bed elevations or water depth could be recorded, the water depth was determined using Google Ocean.

ArcGIS processing

The ArcGIS processing was a multi-step procedure that contained the following steps:

1. Determining the appropriate color value for the border between land and water:
   Each shade of gray was assigned a unique value rather than the default stretched color scale used by ArcMap. Next, using trial and error, the border color value between land and water was identified.

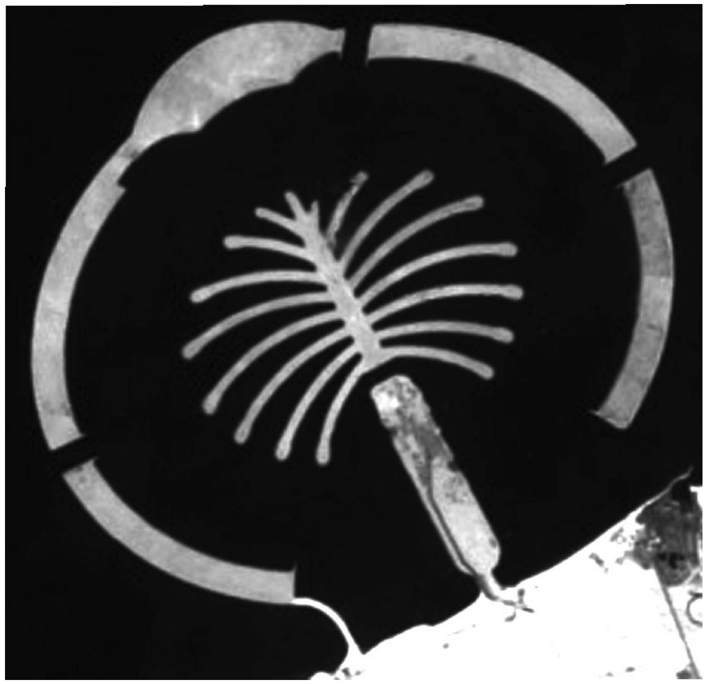
2. Using the raster calculator option in the spatial analyst to obtain a binary raster:
   The color value identified in the previous step was used in the raster calculator to create a conditional statement which would result in a binary raster; all values larger than the border were assigned a new value of one.

3. Creating a TIN of the coastal sea bed using point data contained in seabed feature class:
   The seabed feature class created in the preprocessing phase was the data source for a TIN generated with the 3D analyst extension.

4. Converting the seabed TIN to a raster:
   The 3D analyst was then used to convert the TIN from the previous step into a raster that could be used to perform the cut/fill calculation.

5. Using the 3D analyst to perform a cut/fill calculation:
   Then final step in the ArcGIS processing was carrying out a cut/fill calculation (an option in 3D analyst). The initial condition used was the sea bed raster and the final condition was the binary raster of the island.

The following images depict the process described above (screenshots of ArcMap software were taken and cropped).

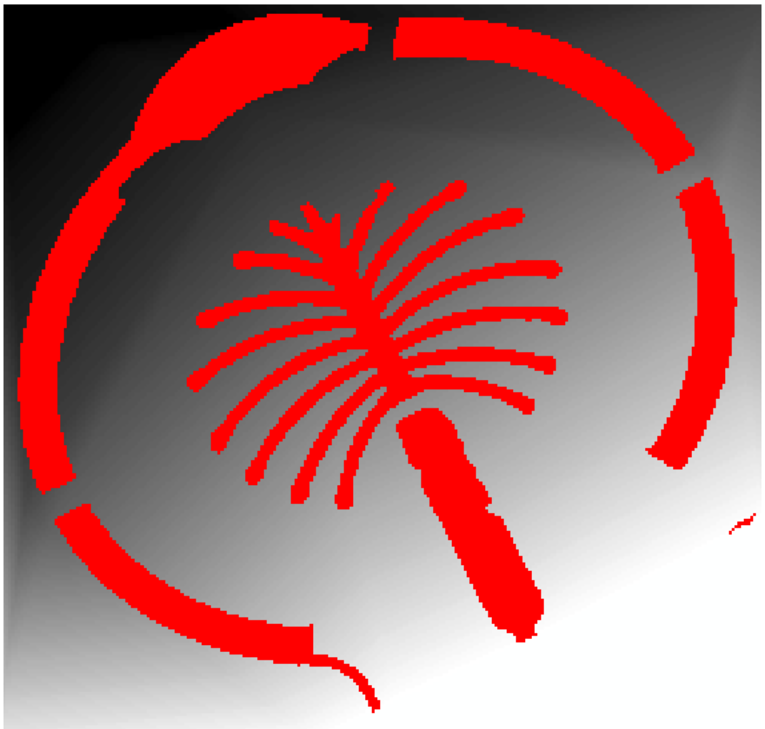


Satellite image of Palm Jebel Ali under construction,2006 (courtesy: NASA ASTER website)

Binary Raster of Palm Jebel Ali

TIN of sea bed created from elevation of Google Ocean (placed underneath binary raster)

Seabed raster created from TIN (placed underneath binary raster)



Results of cut/fill calculation (red volumes specify fill areas)

Results

The 3D analyst divided the island landmass into 6 different parts for the purpose of cut/fill calculation; the following table is the summation of the volumes of all parts.

	VOLUME(m^3)
1	22,218,360.47
2	8,130,737.89
3	3,219,796.87
4	16,432,373.56
5	3,025,359.45
6	3,911,076.85
TOTAL	56,937,705.09

Without a basis for comparison, the result of the cut/fill calculation is meaningless. The geotechnical data along with the construction methods information provided the basis needed for evaluation. The Nakheel group had no information on the Palm Jebel Ali which could be used for comparison, their website did however, contain information on the completed Palm Jumeirah.

The following fact was found on the information page for the Palm Jumeirah:
"An astonishing 92,234,000 cubic meters of sand was then transferred to build up the landmass." (http://www.palmjumeirah.ae/inspired-engineering.php). For comparison, the Palm Jumeirah is a much smaller project than Palm Jebel Ali, but this still does not provide a quantitative basis. The solution was to run a similar ArcGIS processing of the Palm Jumeirah as was done on the Palm Jebel Ali. The calculated volume of the Palm Jumeirah was 51,983,000 cubic meters, nearly 56% of the stated volume.

What are the sources of difference between the two?

First of all, 3D analyst doesn't account for compaction; an average compaction factor for sea sand would be 1.15, using 110 as the dense unit weight and 95 as the uncompacted unit weight or 75% dry relative density. So 51,983,000 would be 59,780,000, still far from 92,234,000.

Second of all, 3D analyst assumes the Island are filled using straight side walls, while this is possible through the use of coffer dams, as mentioned above, the island were constructed by piling the sand and letting it settle with its inherent angle of repose. The angle of repose for moist sea sand is 35 degrees, which is equivalent to a 7 : 10 slope, this would increase the calculated island landmass by a factor of about 1.6, which means 59,780,000 cubic meters are now 95,648,000 cubic meters, closer to stated value with deviations being the result of the angle of repose increase factor.

Following the logic displayed above the incomplete Palm Jebel Ali is currently composed of 103,456,000 cubic meters of sand, or enough to fill 41,382 Olympic size swimming pools.