VECTOR BASED MAPPING OF POLYGONS ON IRREGULAR TERRAIN MESHES FOR WEB 3D MAP SERVICES

Arne Schilling, Jens Basanow, Alexander Zipf
i3mainz - Institute for Spatial Information and Surveying Technology, University of Applied Sciences FH Mainz, Holzstraße 36, Mainz, Germany
[schilling, basanow, zipf]@geoinform.fh-mainz.de

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Abstract: In this paper we show how to efficiently integrate traditional GIS data into terrain models in order to generate complete 3D maps with little overhead for textures. The results meet the requirements for the Web 3D Service (W3DS), a proposal for the standardization for delivering 3D web maps. Our approach is designed to create fully vectorized 3D scenes that deliver the best possible quality and do not require dynamic texture generation and handling. We describe the mesh operations for integrating polygonal GIS data like forests, parks, buildings blocks, or streets into the terrain mesh and compare the results with a texture based approach.

1 INTRODUCTION

In recent years much effort has been invested into the standardization of 3D GIS (Geographical Information Systems) solutions and to make them suitable for web applications. The Open Geospatial Consortium (OGC) plays a major role in this standardization process and has already issued a range of specifications for GIS web services, e.g. a Web Map Service (WMS) or Web Feature Service (WFS). Currently the foundations for exchanging 3D GIS related data structures and graphics over internet protocols are being discussed and first solutions implemented. The new specifications and recommendations include a Web 3D Service (W3DS - OGC 2005) which delivers 3D map display elements that can be explored in real time by any web client, and an information rich data exchange model (CityGML - Kolbe et al. 2005) that is specifically designed for 3D city models. The latter incorporates not only the geometrical description but also semantic information of typical GIS objects.

In order to make a 3D Spatial Data Infrastructure (SDI) work, which is the eventual goal of our activities, it is not sufficient to agree on the technical interfaces. A major research topic is related to the integration and preparation of various data coming from different sources. This refers to the automatic assembly of different Levels of Detail (LODs), integration of official cadastre data (Stoter 2004), terrain-object integration, point object processing, and other problems. In Schilling and Zipf (2002) the authors showed how to apply such integrated visualization models for 3D tour animations.

In this paper we focus on the integration of traditional 2D GIS data into 3D landscape and city models which use terrain models as basic height source. Such models may be referred to as 2,5D, but can be complemented with models coming from 3D databases. The 2D data comes typically from a WFS and must be mapped on the terrain model based on Triangulated Irregular Networks (TIN).

The remainder of this paper is structured as follows. First, we compare different approaches for the integration of 2D GIS data and digital elevation models. Then we briefly explain the technical background and requirements before we go into detail about the geometrical operations of our approach. In the last section we compare our results with an image based overlay.

2 RELATED WORK

We can distinguish 2 general approaches how to display 2D vector data together with surface models.

1) The most common approach is to render vector graphics into an image and to project it on the terrain as texture. Traditional GIS layers, raster data, and sometimes scanned paper maps are overlaid and combined to a single texture layer (e.g. Haeberling 1999). Additionally, hardware accelerated techniques like mip-map filtering and image pyramids can be used to optimize rendering speed and memory consumption.

In contrast to this static method also a dynamic version has been investigated by Kersting and Döllner 2002. They extend the concept of static texture pyramids and introduce on-demand texture pyramids, which are not prepared in a pre-processing step, but rendered for each frame using an off-screen pixel buffer (p-buffer, see also Wynn 2001). The advantage of this method is that huge amounts of texture data that would be necessary for every possible resolution don't need to be transmitted over the network. Instead, only the 2D vector data is being transmitted. Since the p-buffer is hardware accelerated, the images of the texture pyramids can be rendered on demand for arbitrary resolutions.

2) The second approach is a geometry based mapping, i.e. to adapt the 2D vector data to the surface of the terrain model and to render it as separate geometric primitives.

Wartell et al. 2003 show how to overlay 2D polylines on top of terrain models. The overlayed polylines are rendered independently from other image data due to rasterization artefacts. They present the triangle clipping DAG (direct acyclic graph) data structure which allows rendering the projected polylines together with a quad-tree based terrain model. They address the challenging problem of combining progressive terrain meshes, which change at nearly every frame as described by e.g. Hoppe 1998 or Lindstrom and Pascucci 2002, with 3D polyline data, which also needs to adapt accordingly.

Agrawal et al. 2006 use a similar technique for combining a textured terrain model with polyline data. In their case, the terrain is organized as block-based LOD structure derived from a height raster, which allows efficient memory paging and optimized data structures like triangle-strips. Due to this block-based simplification and visualization scheme (9 tiles are visible at one time), height values can be picked up for each line segment from the underlying mesh with the highest resolution. Over meshes with lower resolutions, these height values must be corrected accordingly.

Schneider et al. 2005 show how to handle polygonal GIS data in a similar manner. The polygon borders are treated in a similar way as the polylines described above. The interior of the polygon is triangulated and added to the new geometry, to which a z-offset is added in order to avoid interference with the terrain and rendering artefacts. An overview of earlier works in this field and some foundations on practicable topological data structures is provided by Lenk 2001.

Both approaches have advantages and drawbacks. A naïve texture mapping without dynamic rendering is suitable for remote sensing raster data like satellite imagery. Vector GIS data like streets, borders, and landuse areas require a much higher resolution in order to avoid aliasing and jagged edges. Especially thin lines must be drawn with variable width, otherwise they will be filtered out or look odd in the far distance. Vector integration requires more complex geometric operations and is more expensive in the preparation phase. Overlaying triangulated polygons on top of the terrain causes huge overheads for large areas.

1. WEB APPLICATION FOR 3D MAPS

The presented work is embedded in a larger project that involves a 3D web map server, catalogue services, several clients and the integration of various data sources (see Figure 6 for a screenshot of the web client). We give a brief introduction in the deployed technologies since they provide important implications and also constraints for the presented method for 3D map generation. In this project, among other issues, we implement two technologies that have been proposed to the Open Geospatial Consortium (OGC) as Discussion Papers.

Finally the need for standardization of geographical 3D web services has been acknowledged, which led to the first efforts in that direction. A specification for the delivery of perspective views of digital terrain models has already been accepted, the Web Terrain Server (WTS) – it will be renamed Web Perspective View Service (WPVS) in future versions. Being an image based service, it does not support interactive applications very well. The Web 3D Service (W3DS) goes one step further (OGC 2005). The parameters are similar to those of the WTS. The requested area is described as simple bounding box. Information on available layers and styles is provided by the server using the GetCapabilites request. The GetScene request delivers complete 3D scenes that can be displayed by web browsers or integrated in specialized client software. VRML 2.0 must be supported as basic format, but also other formats can be used. The requested area is described as simple bounding box. Optional parameters include a point of interest, a point of camera and a style for each layer based on the OGC Styled Layer Descriptor (SLD).

The W3DS follows the concept of a medium server & medium client scheme, that is, the server is responsible for the data integration and transfers the display elements to the client, which is rendering the scene in real time. Usually browser plugins that support the specified format are downloaded from third party companies and used for rendering and navigation.

Dynamic concepts like continuous LODs for triangle meshes or streaming of geometry parts are not incorporated, which is on the one hand beneficial for the broad applicability, but on the other hand shows the need for developing standards that cope with classical GIS features as well as techniques that are already state of the art in computer graphics.

In our scenario we need to be able to support desktop computers as well as mobile handsets such as cell phones equipped with 3D graphics chips. Consequently, the scenes that we deliver to the client are static. However, block based visibility schemes, in which complete tiles with variable size and LOD are streamed to the client, are still feasible.

The second important technology that we deploy is the CityGML specification that addresses interoperability problems during data exchange between different systems (Kolbe et al. 2005). It has been developed by the SIG3D (Special Interest group of the Geodata Infrastructure of North-Rhine Westphalia, Germany) and proposed to the OGC in June 2006 as discussion paper. The geometry description is based on the Geographic Markup Language (GML), but furthermore includes materials and textures, prototypic objects, aggregations and 5 predefined LODs. Although CityGML is primarily envisaged to completely describe any 3D city model, and not 2D vector maps, it is mentioned here because some important interrelationships between the terrain model and built objects are addressed. First, it introduces the concept of closure surfaces, which are used to seal holes in the ground. Open structures like tunnels and pedestrian underpasses can be modelled this way. The triangulation of the terrain is not perforated since the closure surface belongs to both object and terrain. Similar to closure surfaces are terrain intersection curves, which describe the exact location where a building is touching the ground. Using these curves, buildings floating over or sinking into the ground can be avoided.

Both kinds of curves need to be integrated into the terrain using a similar method as described in the remaining part of this paper. However, the height values must be taken from the input curves.

2. APPROACH FOR POLYGON INTEGRATION

Reviewing the preconditions above, we can state that

a) dynamic off-screen rendering is not supported by standard web browsers,
b) the amount of transmitted data should be as small as possible, especially when we consider low bandwidth mobile networks,
c) raster images are very inefficient for representing polygonal data.

Therefore, geometric mapping should be preferred over image based mapping. In this paper we pursue an approach that produces fully vectorized 3D maps. Polygonal data sets such as building blocks, green areas, forests, and roads are loaded from 2D GIS layer files and integrated into a custom Constrained Delaunay implementation for the terrain. The main properties of this method is, that the shape of the terrain is not altered, and z-buffer problems do not occur, since the resulting terrain is still a single continuous surface but with integrated areas that represent the input 2D shapes. After the geometrical integration operation we can identify the triangles lying completely inside the area and mark them as owned by the GIS layer the polygon comes from.

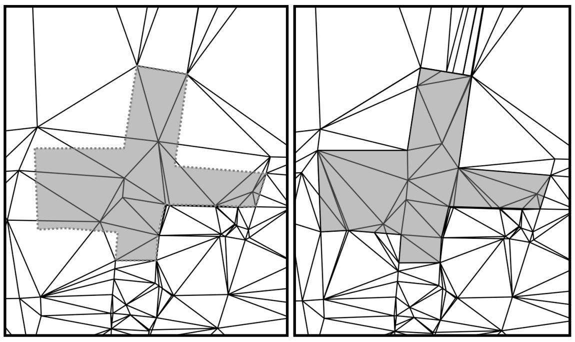


Figure 1: Polygon integration. Comparison of the situations before (left) and after (right) the mesh operations. The area becomes visible when different colours are applied to the triangles.

When the mesh is encoded into the target transmission format, a style (e.g. a layer colour) can be applied to these areas which thus become visible. Figure 1 shows the comparison of the situations before and after all integration operations for one polygon. The edges of the mesh which lie exactly on the polygon border are marked as constrained in order to avoid the destruction of the area by subsequent mesh operations.

It should be noted that in this context "constrained" does not mean that the edge must not be altered at all. It means that the line shape must be preserved. Nodes may still be inserted directly on the constrained edge, splitting it into two and changing the topology. This case occurs regularly, when geometries of different layers lie next to each other, for instance at the transition between different biotopes, at the border between land and water and many other cases.

Geometries of different layers may be overlapping. In this case the last layer will take the ownership of the triangles beneath. Integrating several layers in a specific order will look like painting them on top of each other in a desktop GIS program.

3. MESH OPERATIONS

In order to achieve the result as displayed above, we need to focus on the polygon borders. All vertices can be easily integrated into the mesh, but the connection between them by edges must be treated more carefully, since direct lines might lead to distortions.

The algorithm handles all layer polygons after each other. The first step is to integrate all vertices of the outer and inner polygon boundaries into the triangulated irregular network (TIN) of the terrain. For each vertex v we find the triangle under v.x / v.y and compute the height h value h. The new node n(v.x, v.y, h) is inserted into the TIN and the triangulation is adjusted (Figure 2). All these vertices are now part of the TIN as nodes (called *Constrained Nodes* here).

For all search operations on the TIN it is very important to work with an effective spatial index, otherwise huge overhead computations would slow down the process. We use our own Quadtree implementation optimized for triangle meshes.

The next step is to connect all *Constrained Nodes* by edges. The general approach is to remove all triangles that lie between the two *Constrained Nodes* of a segment and connect them directly with a single edge. The holes on either side of the edge are triangulated afterwards. Although the resulting mesh would seem to be correct from above, it would mean to create a ridge or a trench in the surface.

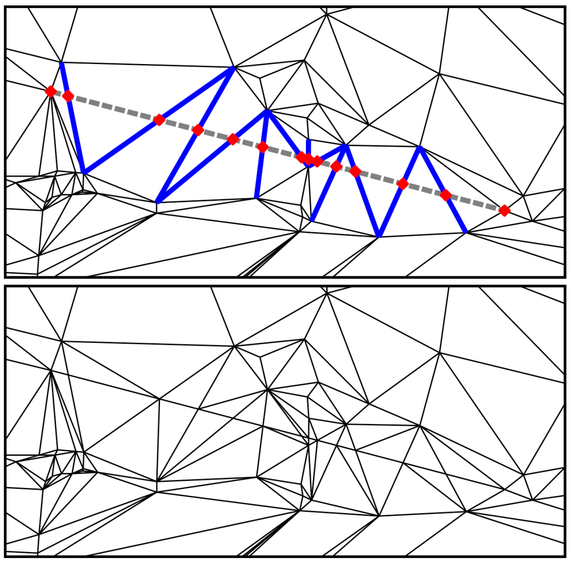


Figure 2: Connecting two nodes by a string of constrained edges. Situation before insertion (top) with the new segment as dashed line and the involved original edges and new nodes in bold style. Situation afterwards (bottom) with the new segment represented by constrained edges.

Therefore, we need to find the intersection points of the segment and existing TIN edges and compute the correct height over the edges (Figure 2). On each intersection point we perform a node on edge insertion operation. This deletes the edge and the adjacent triangles and produces 4 new edges and 4 new triangles. The new nodes can be inserted in a random order. In fact, the order is given by the spatial index which is used to find the triangles beneath the segment and can hardly be predicted. Now we need to find the new edges under the segment and mark them as constrained edges, because their shape should be preserved and not modified by subsequent operations. In order to avoid a relatively costly search on the spatial index, we start with the first *Constrained Node* and look for connected edges in the direction of the segment. This is a topological function and is performed very quickly. The loop is finished when the second *Polynode* is reached.

The last step is to identify all triangles within the polygon and mark them as owned by the layer which is currently processed. For this we use the quadtree again which performs a simple search by the triangle centre points. The following pseudo-code shows the complete loop for one layer.

```
for each polygon p in layer
  for each vertex v in p
    calculate height h over tin at v
    insert new node(v.x,v.y,h) into tin
  end
  for each segment s in p
    n0 = start node of s
    n1 = end node of s
    if n0 and n1 are connected by edge e
      mark e as constraint
    else
      find intersection points I of s with
      edges of the tin
    for each p in I
      calculate height h over edge e
      insert new node(p.x,p.y,h) on e
    end
    n = n0
    while n!= n1
      find edge e lying in direction of s
      mark e as constraint
      n = opposite of n node on e
    end
  end

  find all triangles T of tin within p
  for each t in T
    mark t belonging to layer
  end
end
```

4. GEOMETRY EXTRACTION

Before the finished vector map is transmitted to the web client, the TIN topology must be broken down into an indexed triangle array or triangle strip array. Most formats support a mesh colouring by triangle so that we can distinguish the integrated areas. The other possibility is to put all triangles that are owned by one layer into a separate geometry. Thus we get one geometry per layer (Figure 3). The advantage is that we can apply a different style to each layer. A style can be a simple colour, material, or texture. Especially generic textures for the natural environment like grass or crop areas can improve the visual quality of landscape models enormously, also for map-like non-photorealistic visualizations. Additionally we can better influence the reflectivity for different materials. For instance water surfaces should be rendered using higher shininess values than for wood.

5. VECTOR MAP VS. TEXTURE MAPS

One of our main goals was to reduce the file size of 3D maps as much as possible since they need to be transmitted to Web Map clients within a low bandwidth network. In this chapter we compare the file sizes of vector maps and textured maps with the same content. The map area has an extent of 2x2 km and contains layers for water, wood, parks, and streets. The original DEM consists of 14504 triangles. After the integration of all layers we get 39208 triangles; that is an increase of 170%.

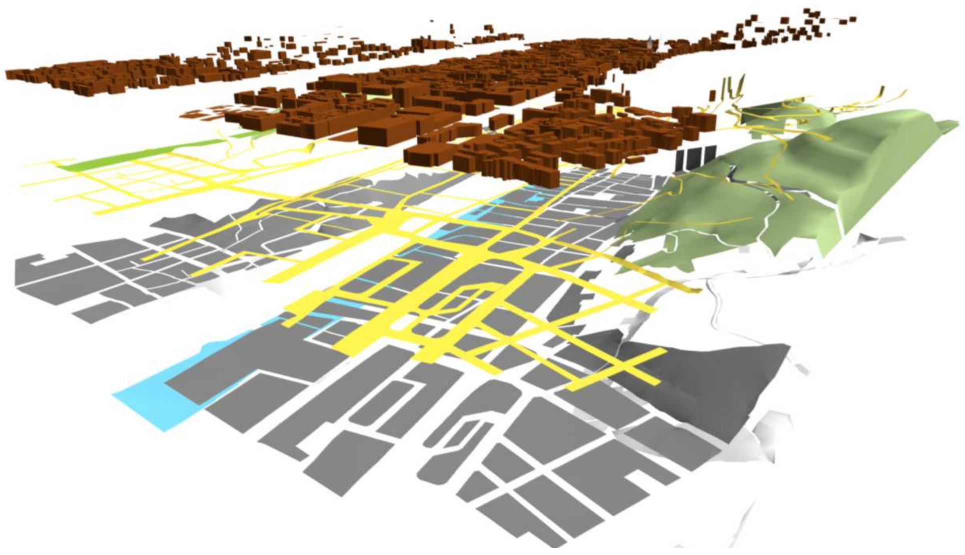


Figure 3: Terrain areas are separated into geometries representing the layers. To each layer geometry a different style can be applied. Buildings are placed on top of the terrain.

This value depends strongly on the relation between the LOD of the digitized areas and the LOD of the terrain. For data sets consisting of larger areas like geological maps, it is much lower.

We found that compressed VRML encoding is the most effective one compared to other compressed ASCII and binary encodings like X3D, 3ds, Viewpoint and others. After encoding the vector map into VRML and performing a standard ZIP compression the resulting file is as small as 414 KB (see Figure 4c).

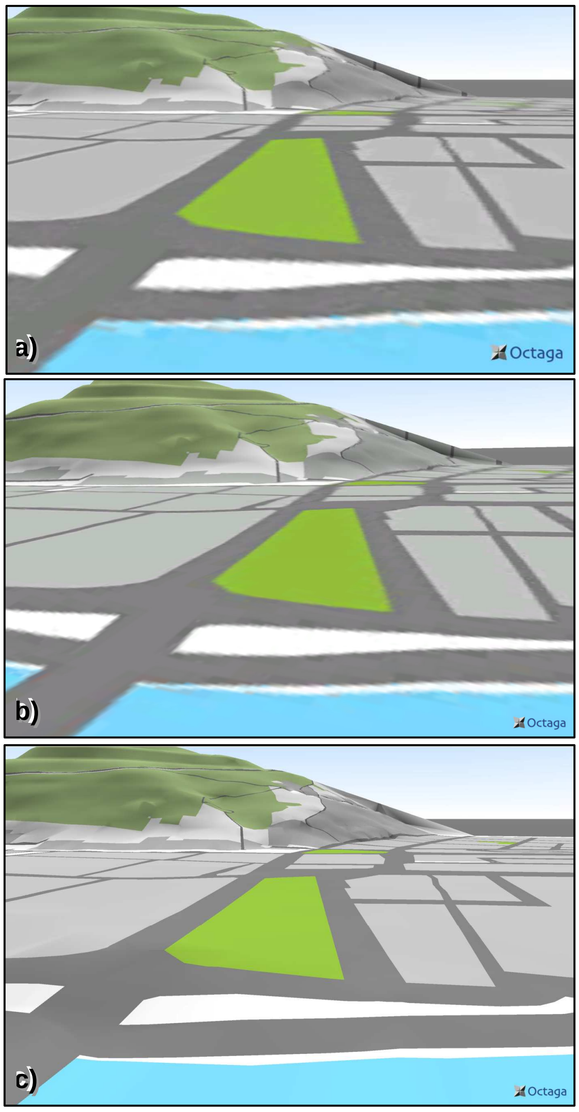


Figure 4: Comparison of texture mapping and geometry based mapping, a) texture map with low resolution, low JPEG compression, b) texture map with high resolution, high JPEG compression, c) vector map with integrated areas.

Additionally to the vector map we produced terrain textures by loading the GIS layers into the commercial GIS package ArcMap and exporting the display as TIFF raster image with maximum resolution. The TIFF was post processed by standard imaging software in order to crop the image to the correct map extent and to create JPEG and PNG textures of various resolutions and JPEG compression ratios. Texture coordinates were calculated by projecting the images from above and added to the scene. Although much more sophisticated texturing schemes are feasible including dynamic texture trees and multi-texturing, comparing to this simple approach is still valid if we consider only a small region, which must be sooner or later rendered everywhere at the highest available resolution if the avatar is exploring the whole scene.

Figure 4 shows a comparison of two different texture maps and the vector map loaded in a standard web browser plug-in. The textures have different resolutions and JPEG compression ratios. The term Texel refers to the pixels of the texture image. The compression ratio is a compound value based on the entries in the Huffman encoding table, ranging from 0 (worst quality) to 12 (best quality).

a) Resolution 1,33 m per texel, JPEG compression 10, file size 413 KB.
b) Resolution 0,5 m per texel, JPEG compression 02, file size 390 KB.
c) Vector map, file size 414 KB.

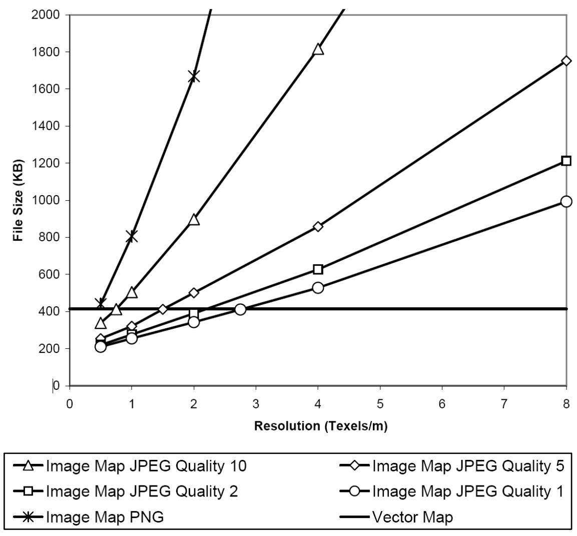


Figure 5: File sizes of texture maps in relation to image resolution and quality compared to the equivalent vector map.

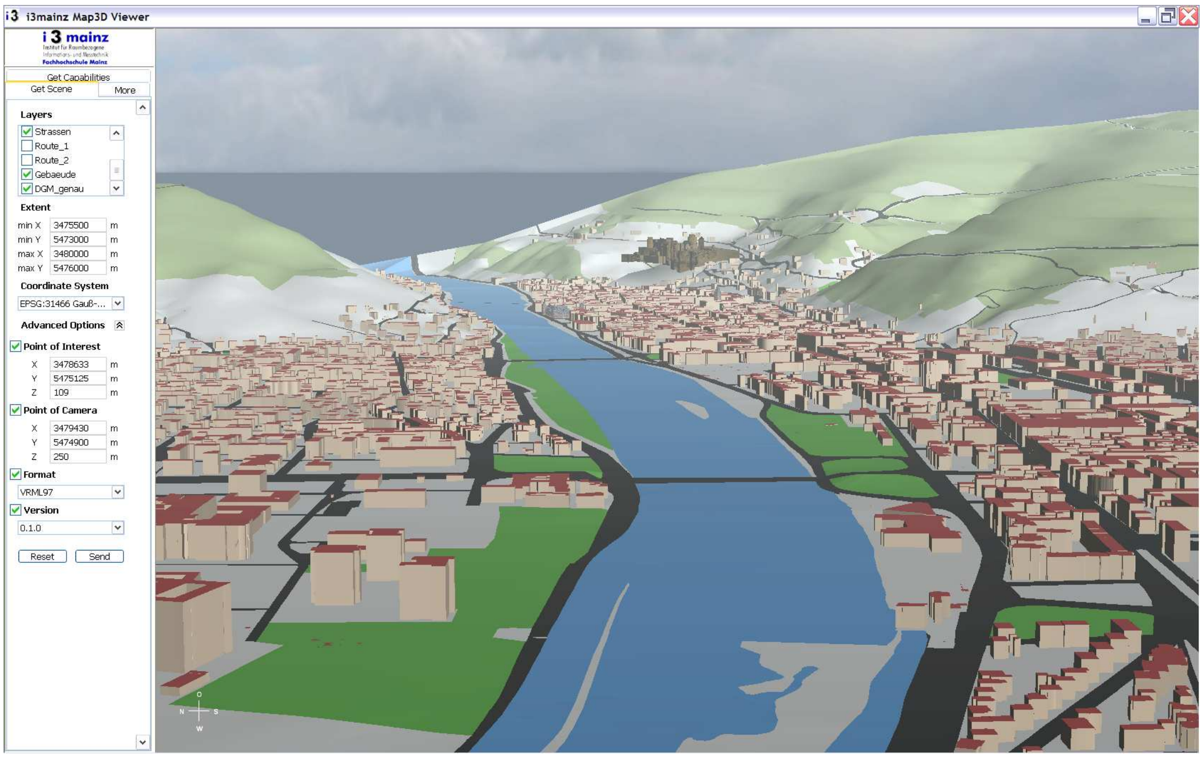
Figure 5 shows how these parameters influence the texture file size. The mentioned file sizes refer to the combined size of compressed VRML and JPEG files. The JPEG textures have also been ZIP compressed. This is usually not done for 3D web applications, since JPEG is very effective for most images. However, in the case of rendered vector graphics the file size could be reduced to 30% - 65% of the original JPEG file, due to the monotonous image structure. As can be seen, the 3 scenes have about the same file size. PNG as an encoding with lossless compression is in general better suited for GIS data, but yields unacceptable amounts of data.

Figure 4 shows that higher resolutions should be preferred when trading off between resolution and image quality. However, only the vector map (Figure 4 c) allows rendering crisp edges.

6. CONCLUSIONS AND OUTLOOK

We showed how to effectively combine 2,5D terrain models and 2D GIS data - especially polygonal data – by using mesh integration operations. We can achieve superior visual quality for representing areas like forests, streets, water, geological strata, and others on terrain models. On the downside, the proposed method involves some additional computations that naturally increase the response time. In our current implementation and for the example above, the polygon integration takes 10 times longer than the initial terrain triangulation. So this should be done in a pre-processing step if possible.

Another important aspect is how to apply mesh reduction algorithms on this kind of meshes for deriving lower LODs or producing hierarchical data structures for continuous LOD streaming (progressive meshes, e.g. Hoppe 1998). Of course, the interior constrained edges should be preserved as long as possible so that the map appearance is not destroyed by edge collapse or vertex removal operations too early. Basically, the error metric needs to be adapted so that alterations of interior edges are charged with a penalty factor. Schroeder 1997 shows how to classify vertices and edges and how to adjust the quadratic error metric.



Layers
- [✓] Strassen
- [ ] Route_1
- [ ] Route_2
- [✓] Gebaeude
- [✓] DGM_genau

Extent

min X	3475500	m
min Y	5473000	m
max X	3480000	m
max Y	5476000	m

Coordinate System: EPSG:31466 Gauß-...

Advanced Options

[✓] Point of Interest

X	3478633	m
Y	5475125	m
Z	109	m

[✓] Point of Camera

X	3479430	m
Y	5474900	m
Z	250	m

[✓] Format: VRML97

[✓] Version: 0.1.0

Figure 6: Screenshot of the final Web 3D Map client. The software runs as Java Webstart application and includes a custom Java3D viewer. Parameters for the OGC GetScene request can be set on the left panel, which include layers, spatial extent, coordinate system, POI, POC and others. Data courtesy of Land Surveying Office City of Heidelberg.

The file sizes of vector maps can be further reduced with mesh compression techniques. Isenburg and Snoeyink 2002 report a reduction of about 50% for gzipped VRML files using an ASCII based encoding of mesh compression.
Higher compression ratios can be achieved with binary encoders that produce optimized bit streams, for instance Delphi (Coors and Rossignac 2004). They use as few bits as possible for describing the mesh connectivity. Another advantage is that such compressed binary formats can be decoded very quickly on the client side, whereas text parsers tend to be very slow and need many resources (esp. XML parsers). We are currently investigating methods to transmit 3D geo data more effectively since we also need to handle complex 3D city models that include buildings, textured landmarks, point objects, and many more. One way could be to describe only the model structure (the scenegraph) in an open format like X3D, and to use compressed binary encoding for the geometry.

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