**3D GIS**

**geometry, semantics, visualization, analysis**

Karel Jedlička

University of West Bohemia

Pilsen, the Czech Republic
Contents

• Introduction
• Motivation
• 3D data
  – Representations
  – Formats
• Workflow
  – CAD -> GIS
  – GIS -> web
  – Big data on the web
• Analysis in 3D
• (3D printing)
Introduction

• **About me**
  - **Qualification**
    - **2010** Ph.D., Postgraduate studies in Geoinformatics VŠB – Technical University of Ostrava.
    - **2000** Ing., Master studies in Geomatics – specialization in GIS University of West Bohemia, Pilsen.
    - **1995** grammar school of Luděk Pika in Pilsen, IT specialization.
  
  - **Research activities**
    - Geomatics, Geoinformatics,
    - Geographic Information Systems (GIS), Geoinformatic Technologies (GIT),
    - Spatial databases, Spatial analysis and modelling,
    - Global Navigation Satellite Systems (GNSS)
    - 3D in GIS
University of West Bohemia
University of West Bohemia
Pilsen

- First mentioned as a castle in 976, as the scene of a battle between Duke Boleslaus II the Pious of Bohemia and Emperor Otto II
- Became a town in 1295 when King Wenceslaus II granted Plzeň its civic charter as a "Royal City,"
- 1945 – liberated from Nazi Germany by the 16th Armored Division of General Patton's 3rd Army.
- 1869 Emil Škoda started up the Škoda Works
- 1842 – first batch of Pilsner Urquell
The University of West Bohemia has eight faculties with more than 60 departments and three institutes of higher education. Nearly 16,000 students can choose from a wide range of Bachelor, Master and PhD study programmes.

1.3. 2016 probíhá od 9 hodin v UN 606 geoseminář na téma Algorithms, methods and techniques for real time GNSS positioning – theory and practice. Prezentovat bude host oddělení Geomatiky, Tamara Ilieva z UACEG v Sofii.
Introduction

Department of Mathematics
Faculty of Applied Sciences
University of West Bohemia in Pilsen
Introduction

3D GIS

The 3D GIS research team focuses on 3D research from 2005. The research started in cooperation with the National Heritage Institute, to fulfill its needs of 3D registers. The history of this research is shortly captured here. Subsequently, the project of Memorial Landscapes Dresden and Terezín as places to remember the Shoah was started in cooperation with the Technical University of Dresden and the Terezín memorial. This page shortly introduces the team and presents its outputs.

Visualization examples

Workshops
The team offers workshops focused on various topics related to three dimensional GIS. These workshops were presented on various occasions, such as conferences or invited lectures at extraneous universities.

http://gis.zcu.cz/aktualni-projekty/3DGIS
Motivation

• **GIS**
  – Approaches to GIS
    • Cartographic/visualization approach
    • Database approach
    • Analytic approach
  – Geographic data
    • Geometry
    • Attributes
  – Geoprocessing tools
    • Data conversions, transformations, ...
    • Visualization tools
    • Analytical

• **3D GIS**
  – Approaches to GIS
    • Cartographic/visualization approach
    • Database approach
    • Analytic approach
  – Geographic data
    • Geometry
    • Attributes
  – Geoprocessing tools
    • Data conversions, transformations, ...
    • Visualization tools
    • Analytical
Motivation

- **GIS**
  - Approaches to GIS
    - Cartographic/visualization approach
    - Database approach
    - Analytic approach
  - Geographic data
    - Geometry
    - Attributes
  - Geoprocessing tools
    - Data conversions, transformations, ...
  - Visualization tools
  - Analytical

- **3D GIS**
  - Approaches to GIS
    - Cartographic/visualization approach
    - Database approach
    - Analytic approach
  - Geographic data
    - Geometry
  - 3D Model
  - Visualization
  - Reconstruction
  - 3D Documentation
  - Virtual reality
  - Part of a database
  - Purpose of a 3D model
Motivation

• 3D GIS – vision

Geometry
Motivation

• **3D GIS – vision**

  CAD based 3D model
  Geometry + colors and textures stored in layers

  **Building**
  ID: 3
  Type: Family House...

  **Roof**
  RoofID: 1
  BuildingID: 6
  RoofType: Wooden
  Orientation: 89°
  Slope: 45°...

  GIS based 3D model
How To built a 3D GIS?

- Geographic data
  - 2,5D x 3D
  - Representations
  - Formats
- Workflows
  - CAD -> GIS
  - GIS -> web
  - Big data on the web
- Analysis in 3D
Geographic data

• Geodata
  – 2,5D x 3D
    or
  – 2,5D and 3D?
Geographic data

• 2,5D data
  – raster
  – Irregular triangular network (TIN)
  – Extrusion of 2D features

• 3D data
  – Wireframe
  – Boundary representation
  – Volume
Geographic data

• 3D representations
Geographic data

• 3D data formats

Wire frame
- dxf
- dgn

Boundary
- (City)gml
- dae
- kml
- skp
- multipatch
- X3D
- WebGL

Volume
- csg
- ifc

data formats
data representations
Geographic data

- 3D GIS scene composed just from 2,5D data
Geographic data

• 3D GIS Scene with added 3D data
Workflow

Surveying
- Transforming measurements to coordinates

CAD
- Drawing 3D models

GIS
- Maintenance
- Analysis
- 3D visualization

Interoperability tools
- Data transfers

3D on Web
- Visualization in a browser
Workflow

Photogrammetry
- Photogrammetric SW
- (rasters, XYZ)

Geodetic Survey
- Surveying SW
- (shp)

GNSS Survey
- GNSS calculation
- (XYZ)

CAD
- (dgn, dxf)
- (scanned rasters)

GIS
- geographic database
- (XYZ)

Web

Architectural drawing

Laser scanning

Point Cloud processing sw
CityGML

• From CAD to GIS
  – CityGML
CityGML

• A common information model for the representation of sets of 3D urban objects.
• CityGML is realised as an open data model and XML-based format for the storage and exchange of virtual 3D city models.
• It is implemented as an application schema for the Geography Markup Language 3 (GML3), the extendible international standard for spatial data exchange issued by the Open Geospatial Consortium (OGC) and the ISO TC211.
• CityGML is intended to become an open standard and therefore can be used free of charge.
• In July 2007 the OGC Technical Committee approved the CityGML specification as an OGC adopted Best Practice Paper on their meeting in Paris.
• The members of the Open Geospatial Consortium, Inc. (OGC) have adopted version 1.0.0 of CityGML as an official OGC Standard in August 2008 (official OGC press release).
CityGML

• Homepage
  – http://www.citygml.org/

• OGC Standard
  – http://www.opengeospatial.org/standards/citygml

• Software
  – http://www.citygmlwiki.org/index.php/Free_Software
  – …
CityGML

• **Taxonomies and aggregations**
  - Digital Terrain Models as a combination of (including nested) triangulated irregular networks (TINs), regular rasters, break and skeleton lines, mass points
  - Sites (currently buildings; bridges and tunnels in the future)
  - Vegetation (areas, volumes and solitary objects with vegetation classification)
  - Water bodies (volumes, surfaces)
  - Transportation facilities (both graph structures and 3D surface data)
  - Land use (representation of areas of the earth’s surface dedicated to a specific land use)
  - City furniture
  - Generic city objects and attributes
  - User-definable (recursive) grouping
CityGML

• Multiscale model with 5 well-defined consecutive Levels of Detail (LOD):
  – LOD0 – regional, landscape
  – LOD1 – city, region
  – LOD2 – city districts, projects
  – LOD3 – architectural models (outside), landmarks
  – LOD4 – architectural models (interior)
## Level of detail

<table>
<thead>
<tr>
<th>Model scale description</th>
<th>LOD0</th>
<th>LOD1</th>
<th>LOD2</th>
<th>LOD3</th>
<th>LOD4</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>regional, landscape</td>
<td>city, region</td>
<td>city districts, projects</td>
<td>architectural models (outside), landmark</td>
<td>architectural models (interior)</td>
</tr>
<tr>
<td>Class of accuracy</td>
<td>lowest</td>
<td>low</td>
<td>middle</td>
<td>high</td>
<td>very high</td>
</tr>
<tr>
<td>Absolute 3D point accuracy (position / height)</td>
<td>lower than LOD1</td>
<td>5/5m</td>
<td>2/2m</td>
<td>0.5/0.5m</td>
<td>0.2/0.2m</td>
</tr>
<tr>
<td>Generalisation</td>
<td>maximal generalisation (classification of land use)</td>
<td>object blocks as generalised features; &gt; 6*6m/3m</td>
<td>objects as generalised features; &gt; 4*4m/2m</td>
<td>object as real features; &gt; 2*2m/1m</td>
<td>constructive elements and openings are represented</td>
</tr>
<tr>
<td>Building installations</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>representable exterior effects</td>
<td>real object form</td>
</tr>
<tr>
<td>Roof form/structure</td>
<td>no</td>
<td>flat</td>
<td>roof type and orientation</td>
<td>real object form</td>
<td>real object form</td>
</tr>
<tr>
<td>Roof overhanging parts</td>
<td>-</td>
<td>-</td>
<td>n.a.</td>
<td>n.a.</td>
<td>Yes</td>
</tr>
<tr>
<td>CityFurniture</td>
<td>-</td>
<td>important objects</td>
<td>prototypes</td>
<td>real object form</td>
<td>real object form</td>
</tr>
<tr>
<td>SolitaryVegetationObject</td>
<td>-</td>
<td>important objects</td>
<td>prototypes, higher 6m</td>
<td>prototypes, higher 2m</td>
<td>prototypes, real object form</td>
</tr>
<tr>
<td>PlantCover</td>
<td>-</td>
<td>&gt;50*50m</td>
<td>&gt;5*5m</td>
<td>&lt; LOD2</td>
<td>&lt; LOD2</td>
</tr>
</tbody>
</table>

... to be continued for the other feature themes

Tab. 3: LOD 0-4 of CityGML with its accuracy requirements (source: Albert et al. 2003).
CityGML

- Level of detail – buildings

Fig. 30: Building model in LOD1 – LOD4 (source: Karlsruhe Institute of Technology (KIT), courtesy of Franz-Josef Kaiser).
• Building – data model (in UML)
CityGML

• Data model – buildings
CityGML

• Data model – buildings

- Site
- AbstractBuilding
- BoundarySurface
  - RoofSurface
  - WallSurface
  - GroundSurface
  - ClosureSurface

LoD-1
LoD-2
CityGML

- Data model – buildings
CityGML

- Data model – buildings

CityObject

Site

MultiSurface

FloorSurface

CeilingSurface

InteriorWallSurface

Opening

Room

BoundarySurface

Door

Window

BuildingInstallation

LoD-1

LoD-2

LoD-3

LoD-4
CityGML

- From CAD to GIS (From SketchUp to ArcGIS)
CityGML

- From SketchUp to ArcGIS
- Data Interoperability
CityGML

- From SketchUp to ArcGIS
3D formats for web visualizations

- From GIS to Web
  - KML+Collada, 3DS, WebGL, ...?
Comparison of various approaches of 3D visualization in the Web Environment

This web page shortly compares various approaches of 3D visualization in the web environment from the point of view of geodata visualization. Looking to the jungle of various ways of 3D data visualization, there are various starting points, e.g. describing particular projects, introducing various clients and complex solutions, distinguishing types of perception or describing languages, whose allow to store 3 dimensional data.

The last mentioned starting point has been selected for those pages and following languages were selected to compare:

- VRML
- X3D
- KML
- DAE
- WebGL
- HTML5
- CityGML
- O3D
- XML3D
- Flash 3D
- SilverLight

Created for purposes of meeting of ICA Commision on Maps and Internet, Pilsen, 2013
3D formats for web visualizations

Extensible 3D - Hello Cube

Basic description
X3D is a royalty-free open standards file format and run-time architecture to represent and communicate 3D scenes and objects using XML. It is an ISO ratified standard that provides a system for the storage, retrieval and playback of real-time graphics content embedded in applications, all within an open architecture to support a wide array of domains and user scenarios.

Example

Code

```xml
<X3D xmlns="http://www.web3d.org/specifications/x3d-namespace" showStats="false" showLog="false"

<Scene>
  <Viewpoint position='0 0 3' />
  <Shape>
    <Appearance>
      <Material diffuseColor='0.5 0.5 0.5' />
    </Appearance>
    <Box DEF='box' size='1 1 1'/>
  </Shape>
</Scene>
</X3D>
```

Useful links
- X3D official wiki
- Specifications related to X3D
- X3D for Web Authors Examples Archive

WebGL - Hello Cube

Basic description
WebGL is a cross-platform, royalty-free API used to create 3D graphics in a Web browser. Based on OpenGL ES 2.0, WebGL uses the OpenGL shading language (GLSL), and offers the familiarity of the standard OpenGL API. Because it runs in the HTML5 Canvas element, WebGL has full integration with all Document Object Model (DOM) interfaces. WebGL is a DOM API, which means that it can be used from any DOM-compatible language. Javascript, Java, and you embed WebGL into applications on a Mac—Objective C. Major interest vendors Google (Chrome), Opera (Opera), Mozilla (Firefox), and Apple (Safari) are members of the Khronos consortium WebGL Working Group. Along with many other 3D graphics developers.

Example

```html
HelloCube.x3d - source code of the example, adopted from here
Geo related example
```

The example below on this page is written using Three.js JavaScript 3D library. JavaScript 3D libraries are libraries written in JavaScript, which are used to create and interact with 3D scenes in web browsers.

Useful links
- WebGL official wiki
- Specifications related to WebGL
- WebGL for Web Authors Examples Archive
3D formats for web visualizations

- Web visualization of big 3D data
  - Big 2D data x big 3D data
  - Continuous generalization
  - Level Of Detail
  - Level Of Abstraction

CAD
(dgn, dxf)

GIS
geographic database

Web
(LOD, LOA)
3D formats for web visualizations

• Big 2D data x big 3D data
  – 2D – scale dependent map

  Raster:
  Vector:

Raster pyramid
generalization
3D formats for web visualizations

- Big 2D data x big 3D data
  - 3D – depends on observer
3D formats for web visualizations

- Web visualization of (big) 3D data
  - Continuous generalization
3D formats for web visualizations

• Web visualization of (big) 3D data
  – Let’s talk about Level Of Detail (LOD) in detail.
3D formats for web visualizations

- Multi LOD

```xml
<NetworkLink>
  <Region>
    <LatLonAltBox>
      <south>50.510822</south>
      <west>14.150509</west>
      <north>50.511153</north>
      <east>14.151284</east>
    </LatLonAltBox>
    <Lod>
      <minLodPixels>MIN</minLodPixels>
      <maxLodPixels>MAX</maxLodPixels>
    </Lod>
  </Region>
  <Link>
    <viewRefreshMode>onRegion</viewRefreshMode>
    <href>L412_L1.kmz</href>
  </Link>
</NetworkLink>
```
3D formats for web visualizations

Multi LOD
3D formats for web visualizations

- Web visualization of (big) 3D data
  - Level Of Abstraction (LOA) (J. Döllner)

- Iconic visualization of landmarks, e.g., for localization, orientations, and navigation tasks
- Landmarks are deformed and rotated such that its „best view“ and user’s viewing direction match
- Best view information approximated using viewpoint entropy
Analysis in 3D GIS

- Analysis in 3D
  - Geographic database with 2,5 and 3D topologically correct data
  - Analytical tools
Analysis in 3D GIS

• Data preparation
  – Building footprints
  – DTM, DSM
  – nDSM = DSM – DTM
Analysis in 3D GIS

- Data preparation
  - nDSM
Analysis in 3D GIS

• Data preparation
  – DTM + LOD2 Building models and vegetation (created from nDSM)
Analysis in 3D GIS

• 3D analytical tools
Analysis in 3D GIS

- 3D analytical tools
  - Enclose multipatch (3D topology check: 2-manifold)
Analysis in 3D GIS

• 3D analytical tools
  – Inside 3D ~ spatial query
Analysis in 3D GIS

• 3D analytical tools
  – Intersect 3D ~ topological overlay
Analysis in 3D GIS

• 3D analytical tools
  – Difference 3D ~ topological overlay
Analysis in 3D GIS

- 3D analytical tools
  - Difference 3D ~ topological overlay
Analysis in 3D GIS

• 3D analytical tools
  – Buffer 3D
Analysis in 3D GIS

- 3D analytical tools
  - Near 3D
Analysis in 3D GIS

• 3D analytical tools
  – Visibility calculated from raster
Analysis in 3D GIS

- 3D analytical tools
  - Visibility – calculated using Skyline
Analysis in 3D GIS

• 3D analytical tools
  – Skyline Barrier
Analysis in 3D GIS

• 3D analytical tools
  – Skyline Graph
Analysis in 3D GIS

- 3D analytical tools
  - Sun Shadow Volume
Analysis in 3D GIS

• 3D analytical tools
  – Sun Shadow Volume
Analysis in 3D GIS

• 3D analytical tools – conclusion
3D printing

- 3D print needs
  - 3D topologically correct data: 2-manifold ~ watertightness
Conclusion

• 3D GIS ~
  – Geometry
  – Semantics
  – Visualization
  – Analysis

Thank You!
Questions?

Karel Jedlička (smrcek77@gmail.com, www.gis.zcu.cz)