Applying Geodetic Coordinate Reference Systems in Building Information Modeling (BIM)

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Applying Geodetic Coordinate Reference Systems in Building Information Modeling (BIM)
Motivation BIM and GIS Integration

Locate planned buildings within the regional/global context

- To make use of available geodata within the design and planning phase
- To gain correct stake out data for surveying work on the building site
Geometric Representation of 3D Objects

GIS World

Boundary Representation (B-Rep)
Aggregation of all surfaces surrounding the volume

Especially suitable for acquisition from observations (measurement)

BIM World

Parametric, Sweep, CSG
Combination of volumetric objects by Boolean operations

Particularly suitable for design and construction planning
Problem: Different Coordinate Systems

BIM

- Bottom-up approach: idea for a building → design model/plan → real world (e.g. construction company)
- The aim is the correct representation of a planned building and construction processes
- Representation by relative placement of constructive elements (component-based, generative)

→ Local Project Coordinate System (PCS, WCS)

GIS

- Top-down approach: real world objects → surveying → 2D/3D model (e.g. by governmental agency)
- The aim is the correct representation of real world objects for general purposes (GDI)
- Representation by absolute positioning of topographic elements located on the earth surface

→ Regional/global Coordinate Reference System (CRS)
**coordinate characteristics**

The following coordinate characteristics of the PCS and CRS must be considered when:

- Integration BIM projects with GIS data
- Obtain survey data from a BIM project

<table>
<thead>
<tr>
<th>Linear Unit:</th>
<th>PCS (e.g. local WCS)</th>
<th>CRS (e.g. ETRS89/UTM)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Metric, imperial or none (晫)</td>
<td>scale of national grid (meter)</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Scale/Coverage:</th>
<th>PCS (e.g. local WCS)</th>
<th>CRS (e.g. ETRS89/UTM)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Local (limited), project time</td>
<td>World / Country, long term</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Zones:</th>
<th>PCS (e.g. local WCS)</th>
<th>CRS (e.g. ETRS89/UTM)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>No</td>
<td>Yes, by fixed zones</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Number of Digits:</th>
<th>PCS (e.g. local WCS)</th>
<th>CRS (e.g. ETRS89/UTM)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Small numbers (Origin close to the project site)</td>
<td>Large numbers (7-8 before and 2-3 after decimal point)</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Distortion map projection:</th>
<th>PCS (e.g. local WCS)</th>
<th>CRS (e.g. ETRS89/UTM)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>No (1:1)</td>
<td>Yes (up to ~ 400ppm)</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Distortion due to height:</th>
<th>PCS (e.g. local WCS)</th>
<th>CRS (e.g. ETRS89/UTM)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>No</td>
<td>Yes</td>
</tr>
</tbody>
</table>
• **Horizontal** distances (x/y-plane) and areas - **distortions** due to:
  – projection of the curved earth surface into the plane, e.g. measured distance of one kilometer is up to 40 centimeters longer than calculated between the same points in a GIS
  – height differences between the earth surface and the projection surface, e.g. a bridge of about one kilometer which is planned at a height of about 500 meters above sea level is about 8.5 centimeter longer than the surrounding topography in a GIS

• Hence, this distortions have to be considered during the planning and construction phase using a BIM
Correction of measured distances for UTM map projection

- **Height correction:**
  \[ S_{\text{ell}} = S_{\text{meas}} \cdot \left(1 - \frac{h_{\text{ell}}}{R_m}\right) \]

- **Projection correction:**
  \[ S_{\text{UTM}} = S_{\text{ell}} \cdot 0,9996 \cdot \left(1 + \frac{(E_m - 500\, km)^2}{2R_m^2}\right) \]

- **Combined height and projection correction:**
  \[ S_{\text{UTM}} = S_{\text{meas}} \cdot 0,9996 \cdot \left(1 - \frac{h_{\text{ell}}}{R_m} + \frac{(E_m - 500\, km)^2}{2R_m^2}\right) \]

**Where:**
- \(S_{\text{meas}}\) ... Measured horizontal distance on earth surface
- \(S_{\text{ell}}\) ... Horizontal distance on reference ellipsoid
- \(S_{\text{UTM}}\) ... Horizontal distance in UTM projected CRS
- \(h_{\text{ell}}\) ... Height of earth surface resp. construction/planning site above reference ellipsoid
- \(E_m\) ... Mean easting value of the construction/planning site
- \(R_m\) ... Mean radius of osculating sphere: 6383 km
Applying Geodetic Coordinate Reference Systems in Building Information Modeling (BIM)

<table>
<thead>
<tr>
<th>Project Coordinate System (PCS)</th>
<th>Local Surveying Coordinate System (LSS)</th>
<th>Coordinate Reference System (CRS)</th>
</tr>
</thead>
<tbody>
<tr>
<td>BIM</td>
<td>Engineering Surveys</td>
<td>Geodesy, GIS</td>
</tr>
<tr>
<td>Mensa</td>
<td>Campus</td>
<td>National Grid</td>
</tr>
</tbody>
</table>

- for each building
- in BIM Software
- scale (projection, elevation above ellipsoid)
- "long" geo-coordinates, zone
- GIS / Surveying Software (COGO)

- 3P + Height
- 4P + Elevation

identical object points
identical survey points
Example: Georeferencing in Autodesk Revit

- Given: Autodesk Revit BIM project of the university (Mensa building)
- The Intermediate Local Surveying Coordinate System (LSS) between the BIM PCS and the national CRS has been introduced
  - Provides a common reference system and frame with scale=1 and short coordinate values
  - Allows to integrate multiple BIM projects (e.g. Mensa building, Building A, Building B)
  - The LSS is than georeferenced to a national CRS
Control points

- In order to spatially link the LSS and the PCS, a set of identical points was defined and measured.
- This control points are specified in the BIM model and as natural targets of the engineering survey outside and inside the building.
A BIM model can be georeferenced by moving the Project Base Point (PBP) to a control point with known coordinates.

1. Unclip and move the PBP to the well identifiable corner within the building model which corresponds to the pre-measured control point #2018 using the point snapping function.

2. Clip the PBP and assign the LSS coordinates of the point #2018 to the PBP properties.

3. Insert the pre estimated azimuth angle of 359.5° to the PBP properties.
A BIM model can be georeferenced by acquiring the LSS coordinates from a CAD file containing measured lines and polygons of the building elements

1. Link the CAD file to the Revit project using Revit linking functions
2. Placed the CAD elements (yellow) in the BIM Model (black) graphically by using the “move” and “rotate” tools as well as “Line Snapping” tool
3. Use “AcquireCoordinates” to assign transformation parameters between the Revit PCS and the LSS to the Project Base Point
Georeferencing Using the Plug-In Point Layout

Plug-in “Autodesk Point Layout” (APL) provides functionalities for the surveyor’s work within the BIM, i.e. assigning the transformation parameters from the Revit PCS to the LSS

1. Start the APL tool “Coordinates”
2. Select the desired unit (e.g. meter, millimeter, feet)
3. Click on two control points and enter the corresponding LSS coordinate values
4. The azimuth of the transformation is determined from coordinates

Our aproach with students:
- at least 4 control points
- proper adjustment (reliability!)
- Set transformation (North, East, Azimuth, Height) in PBP
Export Georeferencing Using IFC

Software: Georeferencing a IFC project using the `IfcSite:LocalPlacement`

```
#define T18=IFCPROJECTEDCRS('EPSG:31467','EPSG:31467 - DHDN / 3-Degree Gauss-Krueger Zone 3', 'EPSG:31467', $, 'Gauss-Krueger', '3', #18);
```

**Standard (IFC4): IfcCoordinateReferenceSystem and IfcCoordinateReferenceSystem -> IfcProjectedCRS**

- Name (e.g.: EPSG1234), GeodeticDatum (e.g. ETRS89), VerticalDatum (e.g. AHD)
- Unit, MapProjection, MapZone

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