Integrated Project: SDI Services Implementation

3D-GIS Buildings for communication in 3D-maps

Final report

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Abstract

This project aimed at the definition and validation of a workflow for the conversion of building plans into semantically enriched 3D GIS data. AutoCAD drawings (DWG-files) were used as source data. The drawings were generalized in AutoCAD and enriched with semantic data, using Object Data in AutoCAD Map3D. The prepared AutoCAD data was then transformed with Safe FME to an ESRI file geodatabase and combined with additional data by joining tables. Eventually, a 3D Scene was created in ArcGIS Pro, using extruded polygons. In addition, a Web Scene was created in ArcGIS Online, based on converted multipatch data which was provided as hosted scene layers, based on scene layer packages.

Introduction

This report gives an overview over the activities, milestones and efforts of the project. The report is structured into two main parts. The first part gives an overview of the structuring of the project into individual milestones and tasks, with brief descriptions of each item. The second part is documenting the results of the project.

The original description of the project topic can be found as attachment at the end of this report.

Project goal
The goal of this project is to develop a 3D Model of the building complexes 14 and 15 of the Techno Z in Salzburg. This model will be derived from CAD data provided by the supervisor Manfred Mittlböck. The result of this project aims to help future students to facilitate their orientation in these two building complexes.

Motivation
3D-GIS is becoming more and more relevant as a lot of research is directed towards visualizing and navigating indoor spaces and using 3D-models to enhance classic cartographic presentation, augment reality or create virtual realities based on real data.

Acquiring knowledge in modelling, creating, managing and communicating 3D data can be a big advantage for future job applications.

The prototypic outcome of this project could eventually be used to create a semantic 3D-model of all university buildings, which could for example be used for orientation and navigation, or to visualize sensor data from other projects in their geographical context.

Objectives
There are five main objectives in this project:

- Definition of 2D and 3D data models
- Semi – automation respectively automation of data integration
- Optimization of the data collection
- Working with appropriate databases
- Creation of applications containing 2D and 3D geodata
Integrated Project: SDI Services Implementation Winter term 2016
Topic 1: 3D – GIS Buildings for communication in 3D – maps
Group members: Reinel Bernhard and Schendl Gabriel

Project Management

Milestones
The project was divided into six milestones, each of which was made up of several specific work tasks. Table 1 gives an overview of the milestones and the respective work tasks. A detailed description of the milestones and their tasks is given on the following pages.

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Milestone 1: Project Setup

The first task of the project was the creation of a workplan including milestones and tasks for the milestones. This workplan was presented in the Integrated Project on November 10, 2016 by the group members. The presentation and the workplan were revised based on the comments from the teachers and colleagues until November 17, 2016. Further issues were added to the workplan; issues which were not considered as important were removed from the workplan.

Further, a Gantt Chart (s. Figure 1) was created showing the milestones and their belonging issues. The Gantt Chart also contains the estimated workload for all six milestones and the two progress reports of the project and the individual workload for both group members. The Gantt Chart also contains the timeframes in which tasks were planned to do. Further, responsibilities for the milestones were assigned. The work on milestone 1 was successfully finished with November 17, 2016.

Figure 1: Gantt Chart of the project
Milestone 2: Analysis and Evaluation

The first task of the second milestone was a requirement analysis for the data model, to identify which entities were necessary to represent the data.

Based on this requirements analysis, a first UML class diagram was created in the second step where the entities mentioned before received detailed attributes, to represent the semantics and relationships of the data.

Later in the project, it was necessary to adapt the requirements and the data model because it turned out to be too complex. The focus of the revised data model was on uniquely identifying the objects, to allow for the association of external data from third party sources, while still being able to visualize the data without external data sources. As a result, the data model was simplified.

The third step included the evaluation and selection of a database software. It was decided to use an ESRI Geodatabase in the project to avoid problems with different data formats due to working with ESRI software. Further, the team members oriented on the master’s thesis from Laura Knoth¹ who also decided to use ESRI geodatabase software.

The fourth step was the implementation of the database schema in the dataset.

The fifth step included the selection of an appropriate tool to convert the CAD data, which we got from our supervisor (Dr. Manfred Mittlböck). It was decided to use SAFE FME to follow the approach from the master thesis of Laura Knoth.

The sixth step of the second milestone included the definition and analysis of possible source data formats. It was decided to prepare the data as far as possible in AutoCAD Map3D, generalizing the source drawings and enriching it with Object Data. This was mainly done to allow for easy maintenance, as we assumed that maintainers will be most familiar with AutoCAD.

Further, we had a meeting with Laura Knoth at the Research Studio iSPACE where we had the chance to ask specific questions about uncertainties in our project. This meeting helped us a lot because many open questions were answered.

Milestone 3: Definition of workflow
The first task of this milestone was the identification of essential steps for the workflow and the creation of a UML activity diagram documenting the initial workflow.

The second task of the third milestone was the definition of a strategy for the communication and visualization of the data. The goal was to create a 3D Web Scene which gets visualized by ESRI 3D Scene Viewer in ArcGIS Online. The scene will be established in ArcGIS Pro. In case of problems, an option would be to export an ArcScene document to a 3D Web Scene which can be uploaded to ArcGIS Online and then visualized with the City Engine Web Viewer.

Further tasks in this milestone would have been:

- Defining specific tasks for each step in the workflow
- Defining specific workflow as UML activity diagram
- Definition of maintenance strategies for 3D-models

Due to delays in the project and time constraints, these three issues were canceled. It would have been planned to make a list of tasks for each step of the workflow and to create a more detailed UML diagram. The last task here would have included establishing ways for a longtime storage of 3D models in a database.

Milestone 4: Implementation of workflow prototype
The fourth milestone would have included the following issues:

- Implementation of workflow prototype
- Validation of workflow prototype using test data
- Implementation of communication strategy

Due to delays and time constraints in the project, these three issues were canceled. Otherwise, it would not have been possible to finish the project in time. It was planned to create a 3D Model of a small part of the study object and to create a 3D Web Scene out of it.

Instead, basic tests were conducted to get familiar with the possibilities, constraints and problems to work with and visualize 3D polygon data in ArcGIS. This focused especially on different extrusion settings for the polygons and on multipatch data.
Milestone 5: Validation of workflow
The first task of this milestone included the acquisition of source data for the TechnoZ building complex. Because of communication problems with the building management, AutoCAD DWG-files of the study object were provided by the supervisor. Due to the huge amount of detail in these files, it was necessary to generalize and simplify the drawings. It would have also been possible to use PDF plans as source, which were provided by the secretary of the department.

The second task of this milestone was the creation of a 3D model. This was basically achieved by annotating the drawing objects (closed Polylines) in AutoCAD with elevation and height values.

The third task of this milestone was the semantic enrichment of the 3D model, which was conducted using AutoCAD’s Object Data extension, available in the Map3D version of the software.

The fourth task of this milestone was the storage of the 3D model in a geodatabase. For this task, Safe FME was used to transform the data from the CAD format to an ESRI file geodatabase.

The fifth and last task of this milestone included validation based on communication. The communication was done through the creation of a 3D scene in ArcGIS Pro and a Web Application in ArcGIS Online.

Milestone 6: Finish documentation / dissemination
The first major task of this milestone includes writing this report describing the activities and workflow in the project. For all milestones and tasks, notes were taken during the work and extended later.

The second issue of this milestone is to collect all the deliverables (e.g. Documentation, UML diagrams, results for the Techno Z building complexes 14 and 15) of the project which are going to be submitted.

The third and last task of this milestone includes the submission of the collected deliverables online in Blackboard.

Progress reports
On December 15, 2016, a presentation containing the achieved progress was held in the class. It included descriptions of the finished issues of milestones 1 to 3 and an outlook on the outstanding tasks which are going to be addressed in the second half of the project.

The final presentation was held in the class on January 26, 2017. The focus was on the milestone 2, 3 and 5. The created model of the TechnoZ building complexes 13, 14 and 15 was presented in ArcGIS Pro and ArcGIS Online.
Source Data

For this project, different possible data sources were considered initially, from printed building plans and their digital PDF versions to the original CAD drawing files. More sophisticated data following the BISDM\(^2\) or FISDM\(^3\) data models or Building Information Modelling (BIM) data following the Industry Foundation Classes (IFC) data model were not taken into consideration. This data would have the benefit, that it is already semantically enriched, or does even directly provide 3D information. But as these data models can still be referred to as being rather young it was rather unlikely that we must deal with them in our case. Also, these data models are very complex, serving not only orientation or visualization purposes, but mainly the planning, documentation, construction and management of buildings. Thus, we decided to focus only on “classic” building plans (floor plans) and to convert their information into an own, simplified data model, that fits the projects purpose. Of course, it would always be possible to convert other source data into our data model as well, but it would require a different transformation strategy.

Data acquisition

Initially we asked the TechnoZ facility management for floor plans of the buildings of interest for our project, without success. We then were able to acquire PDF plans from the secretary of our department, which at least would have been better than printed paper plans. Eventually, our supervisor provided us data for the building complex, containing floor plans, vertical plans and sectional drawings. As these were proper CAD drawings (DWG) we also had all measurements available and didn’t need to manually measure ceiling heights, for example. The data package also contained a SketchUp\(^4\) 3D model of the surrounding buildings, which was included in the final visualization.

Data inspection

Even though we were lucky to have the CAD data available as source data, a first inspection of the data unveiled some issues it had (for our purpose).

First, the drawings were way too detailed for our purpose (s. Figure 2). While we were only interested in elements that are necessary for orientation (like walls, doors, rooms, ...) the plans contained detailed information on the layered construction of walls, for example, which we had to generalize. In addition, it contained all the additional information needed for architectural plans, like annotations or a legend, which we weren’t interested in.

Also, the drawings (every floor is in its own drawing file) had no strict structure. While all drawing files were at least structured by using layers to logically group the drawing elements, there were some differences between the drawings in the number and the usage of layers. This required us to identify which layers in each drawing were of interest for us.

The last and maybe major issue with the drawing was, that the drawings were created with the printed plans in mind. Therefore, the drawings were visually correct, but not necessary topologically. This

\(^2\) Building Interior Space Data Model

\(^3\) Facilities Information Spatial Data Model - http://www.fisdm.org/

\(^4\) https://www.sketchup.com
mean, that a lot of the objects in the drawing weren’t defined by associated line strings (polylines) for all their edges, but sometimes only by individual lines for some edges, if other edges were already implicitly defined by other lines. While this is alright for visually interpreting the plans, it was not ok for us, as we eventually needed polygon data (i.e. closed line strings) for every object.

Because of these issues, we decided to extract and prepare the data we needed, by manually redrawing the required elements in AutoCAD, before transforming it to a GIS data format.

Data model

As existing data models were far too complex for the purpose of this project, i.e. the orientation of students, an own data model was developed for this project.

In a first step, the essential entities were identified in a requirement analysis and modelled in an initial UML class diagram (s. Attachments). We decided that the following entities or classes are necessary:

- BuildingOrPart
- Component (Initially called BuildingBlock, but later renamed to avoid ambiguities)
- Storey (Not called floor to avoid ambiguities)
- Space
- Zone
- Material

The class Storey was originally intended to add additional information about a specific storey of a building and to associate components of a building to it. Because this information could easily be added from other data sources, if needed, this class was dropped in the final data model.

The class Material was intended to define specific properties of a components material for visualization or maybe even for analysis. To reduce the complexity of the data model, as we ran into time constraints, the class was removed and replaced by a simple material code attribute in the component class. Of course, it would always be possible to define additional properties of a material for specific purposes later.

In the following, the five remaining classes of the model will be explained in some more detail.

BuildingOrPart is intended to represent the building or part of a building other elements are associated to. It has a recursive reference on itself, so that the class can be used for both entities, while it is possible to distinguish between building parts and the building the parts belong to. To uniquely identify the buildings or building parts, an attribute facilityCode is used. For the recursive association of building parts to buildings, an attribute parentFacilityCode is used. If this attribute is empty, the object is a building, if it has a value it is regarded as part of a building. This class is also defined as geographic entity, representing the footprint of the building or building part. It also has an attribute to define the height in meters and another one to define the elevation relative to ground.

Component is the class which represents the physical structure of the building. It is a geographic element with geometry and represents the footprint of a wall or wall segment, window, or another structural element. Like BuildingOrPart it has attributes for its base elevation relative to ground and its height in meters. It also has the attributes type, which defines what the object represents (e.g. wall, window, roof, ...). A boolean attribute isExterior defines whether the component defines the exterior of the building, which can be used to visualize the building with a reduced level of detail. Attributes buildingOrPartId and storeyOrderId define the building or building part and storey the component belongs to. The storeyOrderId is zero-based (for ground floor) and negative numbers represent basement...
floors. These attributes can later be used for filtering purposes in the visualization, to show or hide a complete storey or building part for example.

**Space**, in contrast to **Component** represents the non-physical parts of a building, like rooms or hallways. It is also a geographic entity with geometry and thus has attributes for elevation relative to ground and height in meters. Its type attribute is used to define the type of space it represents. Like **Component**, it has attributes for a `buildingOrPartId` and `storeyOrderId`. In the initial data model, this class also had attributes for the function (e.g. office), restrictions (e.g. key needed) and access type (e.g. public or private access). These were dropped in the final data model to reduce complexity, as this data could easily be queried from an external source (e.g. a facility information system). For this reason, the attribute `roomId` allows for the identification of a room and can be used as key (maybe in combination with the `buildingOrPartId`) to query an external data source.

**Zone** is the only class that does not represent a geographic object (i.e. it has no geometry associated with it). It is intended to allow for a logical grouping of **Spaces** to represent for example all rooms belonging to a library, or the offices of all members of a research team. This information was added to the data model, as it can be an important information for the orientation of students. In reality this information would probably come from some kind of information system or database. The class has the attributes `shortname` and `longname` to assign a brief name (e.g. an abbreviation) and a more detailed name to a zone. It also has an attribute `description`, which can be used to define additional information. The `type` attribute can be used to define what kind of zone it represents (e.g. a department, or a team). The relationship between **Space** and **Zone** is the only n:m relationship in the data model. This means that a **Space** can be member of multiple **Zones** and a **Zone** can be made up of multiple **Spaces**. Also, this relationship is the only aggregation in the model, as a **Space** must not belong to a **Zone**. In contrast, **Spaces** and **Zones** must always be associated to a **BuildingOrPart**.

In addition to the class entities, the UML diagram also contains a set of enumerations, defining allowed values for the `type` attributes. These enumerations always have a value called `undefined`, for the case, that a type is not needed, and the value `other` for cases that are not covered.

**Template database**

Following the initial data model, a template file geodatabase was created in ArcGIS Pro, with feature classes, tables and relationships representing the entities and relationships. Also, coded value domains were created, according to the enumerations, and applied to the respective data columns, to constrain the allowed values and ensure data integrity. Figure 3 shows the content of this template database.

![Screenshot of the content of the template database](image)

After simplifying the data model and because we ran out of time, the template database was not used. For a proper solution however, a updated version of the template database should have been created and used for the GIS data.
Workflow

For the whole data processing tasks, a workflow was defined using a UML activity diagram. Similar to the data model, we created an initial workflow which was later revised to adopt for experiences we made in the progression of the project. The diagrams of the initial and the final workflow can be found in the attachments.

The workflow is structured into three main parts. The first part defines the steps necessary to prepare the CAD data, which is followed by the transformation of the CAD data to a file geodatabase (GIS data), using Safe FME. The second part addresses all further processing of the GIS data, until the data can be called complete and ready further usage. The third and final part defines the steps necessary to communicate the data in 2D or 3D to the users.

Three main differences were made between the initial and final workflow. We moved the geometric editing from the GIS side to the CAD side, as AutoCAD is better suited for drawing purposes. We also decided to add the semantic data of the geometric entities already in AutoCAD, using the Object Data feature of AutoCAD Map3D, as this simplifies maintenance, expecting that maintainers will be more familiar with AutoCAD. Eventually, we also added a step in the GIS processing part, where we join additional data (non-geometry or external data) to the transformed data from the CAD source.

Preparation of CAD data

This first part of the workflow begins with the acquisition of the CAD data, as this is the foundation of the whole project. In our case, the data was provided by our supervisor, but we also tried to get in touch with the facility management as a more official source of the data. Unfortunately, we had no success in doing so, despite of multiple tries to reach the responsible person.

After the acquisition, it is necessary to examine the data, to know its internal structure and its quality or suitability for the intended use. This step could also include minor adjustments, or improvements of the data or maybe even the combination of data from different sources.

Once the source data has been analyzed, it is necessary to extract the features which are needed for the intended purpose, like walls or windows, building footprints and the footprints of the rooms or hallways. In our case this meant the redrawing of the desired elements in a new CAD drawing on top of the underlying, original drawings, which were imported as overlays. This was done using closed polylines (i.e. first and last vertex have the same location), as this will result in proper polygons in the GIS data after the conversion.

The last step in the CAD part is the addition of the semantic data for the extracted features, according to the data model, leading to the enhanced CAD data, which can then be transformed to GIS data using Safe FME. This data would also be the appropriate place to maintain the geometric data, in case a building changes or is extended.

Enhancement of GIS data

In this second step, the GIS data which was transformed from the CAD data with Safe FME is joined with additional, non-geometric data. This refers especially to the Zone data, but can also address additional data from external sources. The result of this step is the enhanced GIS data which can be used for the visualization in the final part of the workflow.

Definition of Communication

The final part of the workflow is the communication or visualization of the prepared data. This includes the definition of a symbology, using associative colors and other properties (like transparency) based
on the object types and material definition, for example. Also, for a 3D representation, the extrusion of the polygons must be defined in this step, using the height attributes, to create 3D objects from the two-dimensional polygons.

Data preparation in AutoCAD Map3D

Because the CAD drawings, which are used as source data, were far too detailed (e.g. walls defined as multiple different layers, like concrete, insulation and dry-wall) and only visually correct, but not topologically (objects not defined as closed polylines or polygons), a preparatory step was necessary. In this step, a new drawing was created in which the needed objects were redrawn, on top of the original, underlying drawings (imported as external references). This re-drawing also included the generalization of the high detailed source data to simpler elements and in some cases also a simplification of the shape of elements.

Figure 4 (source data) and Figure 5 (extracted data) show the amount of generalization that was applied to the source data.

The data for all floors of the building of interest (TechnoZ 10 - 15), which was spread over multiple source files, was combined in one drawing. This drawing was organized in different layers and layer groups, based on the storey and element types, to counteract the problems that arise with stacked drawing elements on different storeys, that complicate the selection of individual objects. Thus, it was necessary to pay strict attention to draw on the correct layers.

Also, the elevation relative to ground was set for each drawing element, using the intended elevation property for polyline objects in AutoCAD. In case of a few elements that were drawn as circles, the Center Z property was used, as these elements don’t have an elevation property. However, this doesn’t make a difference when transforming the data with FME. Once the elevation properties are defined, it is also possible to verify the drawing or select elements using the 3D views of AutoCAD, in which the polylines will then float at the defined elevation.

Definition of semantic data witch AutoCAD Object Data

In addition to the geometry and elevation of the drawing elements, semantic data was also added in AutoCAD, using the Object Data extension, which is only available in the Map3D and Civil3D versions.

AutoCAD Object Data is not unlike feature types in GIS data. But while feature types allow for the association of one (or in
some systems also more than one) geometry per data entry, AutoCAD allows the association of one or more data entries (of the same or different table definitions) per geometry (i.e. drawing object). One drawback in AutoCAD is, that there is no easy solution to identify objects that have no object data attached or to identify objects with multiple associated data entries. Therefore, it is necessary to work thoroughly and take care that every drawing object has one and only one entry of object data associated, for the respective class, as the transformation to GIS data is centered on the object data entries and multiple or missing object data will result in duplicated or missing geometries in the GIS data.

Before object data can be associated to drawing objects, object data tables must be defined via the “Define Object Data” dialog (s. Figure 6). In our case, one object data table was created for each of the geometry classes from the data model, with attributes, according to the data model. Once these object data tables are created, new table entries can be attached to the drawing objects. Then, the values of the entries can be set via the properties tool window, like other drawing object properties too. Similar to these properties, it is possible to set the same values for multiple selected drawing objects. Figure 7 shows an example for the properties of a drawing object with an associated object data entry for the Space class at the bottom.

Georeferencing in AutoCAD
One problem when using CAD data in GIS is the usage of different coordinate reference systems. While the CAD data is usually stored in a local Cartesian coordinate system, with XY-Coordinates based on a drawing specific coordinate origin, the GIS data is stored in geographic or projected coordinate reference systems based on a global coordinate origin. Thus, it was necessary to geo-reference the CAD data to move it to the correct geographic position.

AutoCAD usually offers the possibility to define a geographic or projected coordinate reference system and a geographic location, by setting a geographic marker and define an orientation, to reference the drawing in geographic space while still retaining the local Cartesian coordinates. Unfortunately, we had problems using this method in the Map3D version, as this version seems to expect that the drawing coordinates are directly geographic coordinates. At least in our case, the position and orientation of the geographic marker was always lost after reopening the drawing and the direct use of geographic coordinates would have led to problems with the overlay of the source drawing files. Thus, we decided to use a solution for referencing the drawing data during the transformation in FME.

Data transformation with Safe FME
For the transformation of the CAD data to GIS data we decided to use the ETL5-tool FME Desktop from Safe Software. This tool can open a multitude of different data sources, apply transformations on the data and store it in the same or a different format.

---

5 Extract, Transform, Load
Figure 8 shows the workflow we used for the transformation in FME. On the left side are the input features, coming from the CAD data, on the right side are the output features, going to the file geodatabase and between the individual inputs and outputs are the transformation nodes, applied to the data.

![Figure 8: Overview of the transformation workflow in FME Desktop.](image)

**Data Readers and Writers**

We used the reader for Autodesk AutoCAD Map 3D Object Data, which has the option to group the drawing data based on the associated object data table entries (s. Figure 9). This means that all drawing objects without associated object data will not be handled by the transformation, while all drawing objects with multiple entries in the same or different object data tables will be loaded multiple times (once for each object data entry). While this might sound problematic at first it is not that big of a problem, but requires that the person editing the CAD data pays some attention when handling the object data associations. While the default setting for attaching a new object data entry to a drawing element is to overwrite an existing one (if an entry in the same table already exists) it is more likely that the editor might forget to attach object data to a drawing object which will subsequently exclude it from the transformation to the GIS data. Also, the setting to read polylines as 2.5D must be set, to read the elevation values of the polylines, that were set in the CAD drawing, and export them as Z values to the GIS data.

For the output, we used a writer for ESRI file geodatabase based on ArcObjects (GEODATABASE_FILE). This writer was set to overwrite existing geodatabases, and to use Z values. Also, the output coordinate system was set to WGS84. For every input feature from the CAD file, an output feature in the file geodatabase is defined. The feature class definitions, i.e. the attributes for the feature classes, are automatically created based on the object data definition of the input data. A cleaner and more strict solution would have been the usage of a geodatabase template for the output writer and an explicit mapping of the input attributes to the attributes defined in the template geodatabase. Due to time constraints, we were not able to follow this approach and used the more lenient but also error prone way of the implicit definition of the output feature attributes.

The transformation from the closed CAD polylines and circles to GIS polygons is done automatically by FME. But there would also be tools to take manual control of this process, or for example to close open polylines or output information on such errors in the source data to separate files, for inspection.
Data transformation
The data transformation is based on five steps in series, for each feature type. As the settings for the transformation nodes are similar between the feature types, user parameters were used instead of directly setting the value in each tool. This reduces redundant inputs, simplifies changes of settings and reduces the risk of false inputs.

At first, a Scaler is used, to convert the units of the drawing from millimeters to meters, which equals a multiplication of each coordinate with 0.001. This step is necessary as we are later using a Gauss-Krüger coordinate reference system to reference the drawing objects in geographic space. The Gauss-Krüger coordinate system will be based on a meridian which is ideal for the geographic area the building is in and uses Cartesian coordinates in meters. We can use this circumstance to move and rotate the drawing objects to put the building at its correct place, once we manually identified the necessary parameters for the translation and rotation.

For this referencing in geographic space, a Affiner node is used, which executes a affine transformation on the input data, based on user defined coefficients for translation, rotation and scale. The necessary values for the translation and rotation of the data were determined manually, by exporting the origin of the CAD drawing together with the drawing data, assigning the appropriate coordinate reference system and moving the data visually to the correct position and rotation, based on aerial imagery. While this process works in our case, it has some drawbacks. The visual estimation introduces an unknown error to the data. Also, the use of specific transformation coefficients won’t allow to use this FME workflow for other buildings / source data. The best solution would be to have the georeferenced stored in the CAD data, so that the FME workflow can be more generic.

After the affine transformation, the coordinate system of the data is set to MGI-AT/a.M31/GKa, which is a good choice for the location of the TechnoZ building, using a CoordinateSystemSetter. This step does not re-project the coordinates but only label the existing coordinates as being based on this reference system. Of course, the coefficients for the affine transformation were also determined based on this CRS. The order of this step is not crucial, as long as it happens before the final re-projection of the data to the target CRS.

Following the definition of the CRS, a GeometryFilter was used to only pass polygon objects to the writers. While this step should not be strictly necessary, the filter could be used to output all unfiltered, not matching elements to a separate output, supporting the identification of possible errors in the source data.

The last step, before writing the data to the file geodatabase is the re-projection of the coordinates to WGS84 using an ESRIReprojector node with the appropriate transformation selected for the region of interest, were the building is located. The data is transformed to WGS84, as this CRS is required by ArcGIS for the creation of 3D scenes.

Enhancement of GIS data in ArcGIS
The final step of the data preparation workflow, before being able to use the data for visualization is the addition of non-geographic data. According to our data model, this is the Zone data, but additional data that could be useful for specific purposes can be added as well in this step.

In our example, we created data tables for additional data, defining characteristics of Space data, BuildingOrPart data, and Zone data. We also created a relationship table that associates Spaces and Zones. In a real-world example, this data could potentially come from some kind of facility information.
service and the task of joining these tables with the geographic data could be executed using a model or python script, to foster automation.

**Visualization with ArcGIS Pro**

The visualization of the transformed and enhanced data was achieved using ArcGIS Pro, to create a 3D scene and export the data to create a Web Scene and Web Application on ArcGIS Online. A two-dimensional map representation was not defined due to time constraints.

In ArcGIS Pro, a 3D scene was created, defining 3D layers for each building or building part and storey, using definition queries in the layer settings. To convert the flat polygons to 3D data, an extrusion to a base height was set in the “Appearance”-Ribbon of the layer, using the height value from the attributes of the data as extrusion height.

Because all elevation or z-values of the source data are relative to ground, the data is initially placed under the surface. To move the data to the correct elevation, we initially set the elevation setting of the layers to be relative to ground, using geometry z-values. The problem with this setting was, that it skewed the polygons, as the ground (i.e. the elevation data in ArcGIS) is not flat, and thus resulted in the vertices of the polygons not being aligned in one plane. This in return resulted in some visual triangulation problems of the surfaces of the extruded polygons and to major problems in the conversion to multipatch features, which we needed for the creation of a Web Scene, as can be seen in Figure 10. To solve this problem, we used the elevation setting “At an absolute height”, using geometry z-values and added a cartographic offset of 416.6 meters, lifting the data to the correct height, which is also defined as ground level in the source CAD drawings.

A symbology was created for the Component data, based on the material definitions in the data, that looked somewhat realistic and even used transparency for the windows. This symbology was applied to all Component layers. In addition, the Space data was used to visualize the interior of the building. Because the Space data was joined with the Zone data, we were able to highlight these zones in different colors in the visualization, as can be seen in Figure 11. As this visualization is only a proof of concept, a similar method could be used for example in a 3D campus information system, to highlight a specific room or zone the user is interested in and searched for, based on our data model.
Figure 12 shows the final visualization of the 3D model, together with contextual buildings of the TechnoZ campus. These 3D models were provided as a SketchUp model and imported into the ArcGIS 3D Scene via an intermediate conversion to the KMZ format.

![Figure 12: Visualization of the final model, with contextual buildings that were provided as SketchUp model.](image)

**Visualization of varying levels of detail**

The data model also enables the visualization of the data with different levels of detail. This is based on the representation of the footprints in the `BuildingOrPart` class and the `isExterior` attribute in the `Component` class. Table 2 shows a comparison of the different levels of detail. These levels of detail could for example be used on different zoom levels in an application.
### Table 2: Different levels of detail for the building representation.

<table>
<thead>
<tr>
<th>Level of Detail</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Using building footprints</td>
<td>(one height for whole building)</td>
</tr>
<tr>
<td>Using building part footprints</td>
<td>(individual height for building parts)</td>
</tr>
<tr>
<td>Using <code>isExterior</code> attribute</td>
<td>(only exterior components displayed, no internal details)</td>
</tr>
<tr>
<td>Using all <code>Component</code> data</td>
<td>(full detail of the data model)</td>
</tr>
</tbody>
</table>
Creation of Web Scene

The creation of the Web Scene and Web Application were based on the 3D Scene from ArcGIS Pro. Because we had problems with the presentation of extruded polygons when creating a Web Scene directly out of ArcGIS using the “Share as Web Scene” function, and another option with creating an ArcScene document from the Techno Z building complexes and to create a 3ws – file out of it with the tool “Export to 3D Web Scene” and upload it to ArcGIS Online seemed to be antiquated, we used a rather complicated approach.

After defining the 3D Scene in ArcGIS Pro, every 3D layer was converted from extruded polygons to multipatch data (i.e. “real” 3D data) using the tool “Layer 3D to Feature Class”. As mentioned above, this worked only properly when setting the layer’s elevation setting to use absolute height with a cartographic offset, as the skewed polygons that resulted from a relative-to-ground setting led to errors in the conversion to multipatches, as can be seen in Figure 10.

From the resulting multipatches, scene layer packages were created in ArcGIS Pro using the tool “Create Scene Layer Package”. The scene layer packages were then uploaded to ArcGIS Online and hosted scene layers were created for each scene layer package.

In the Scene Viewer of ArcGIS Online, a Web Scene was created with the hosted scene layers. Based on this Web Scene, a Web Application (s. Figure 13) was created in ArcGIS Online. Two options were possible here: using a Template or the Web App Builder. The second option was taken because the Template offered no possibility to switch certain layers on or off.

![Figure 13: Screenshot of the created web application.](http://agibr.maps.arcgis.com/home/webscene/viewer.html?webscene=d09352c4d435433b95569e7239cbe463)

Please note, that the Web Scene and thus also the Web Application were created based on an earlier version of the data model and not the final data model.

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6 http://agibr.maps.arcgis.com/home/webscene/viewer.html?webscene=d09352c4d435433b95569e7239cbe463
7 http://agibr.maps.arcgis.com/apps/Styler/index.html?appid=893573ed7b194c97b7eeb5ab29f62b53
Conclusion

Even though we managed to find and define a semi-automated workflow for the conversion of CAD drawings to a data model that can be used for a 3D visualization and should fit the needs for applications that focus on supporting student orienting in campus buildings, the result is not totally satisfying.

While having at least some automation in the workflow in using FME for the data transformation, it would be nicer to find a way to eliminate the source data specific parameters, concerning the geo-referencing steps in the FME workflow, and to move this information to the CAD drawing as well.

Sadly, we had to find shortcuts in certain stages of the project and omit certain requirements of the project topic, as we ran into time constraints and tried to cover at least the whole topic from the source data to the visualization, leaving certain aspects aside. These time constraints were in part caused by one team member leaving the team right after project kick off and by illness of the team members. But also, some misconceptions in the planning of the project and estimation of efforts for the tasks are to blame. Especially the time needed to get acquainted with the source data (and its peculiarities) and the used tools was somewhat underestimated.

Finally, we are still pleased with the 3D visualization that we got as result of the project and also the possibility of the data model to represent different levels of detail.
Integrated Project: SDI Services Implementation Winter term 2016
Topic 1: 3D – GIS Buildings for communication in 3D – maps
Group members: Reinel Bernhard and Schendl Gabriel

Attachments

Original project description
Topic I: 3D-GIS buildings for communication in 3D-maps

Short Description
Provision of 3D maps becomes more and more important to support different application needs and fosters better orientation capabilities.

The objective of this project is to design, implement and validate an SDI workflows and its architecture for creating, integrating, organizing and communicating 3D building information (indoor & outdoor) for supporting 3D-GIS Mapping applications e.g. supporting orientation from the students perspective.

The project comprises of following steps with according documentation:

- Defining the content that shall be managed with your 3D buildings (as UML model) and subsequently define
  - The 3D data model you’ll use or your building(s) including a basic model and extended data model
  - Choose the appropriate 3D Geodatabase software (e.g. ESRI Geodatabase, Oracle Spatial or Postgres/PostGIS)
  - Implement the according database schema in the dataset
- Define and prototype the (semi-)automatic/manual workflows for managing your 3D Building models (using UML Activity Diagrams)
  - Integration of existing source information (e.g. from CAD) or own data collection (e.g. from .pdf plans) into your 3D-building data model
  - Implement and validate your (semi-)automatic/manual workflows (support e.g. using Safe FME, GeoKettle, documenting manual steps etc.)
  - Define maintenance strategies for your 3D-models
- Validation and communication
  - Define the communication strategy for your 3D-buildings (e.g. Desktop, Web-Service/Application Virtual reality etc.)
  - Validate your 3D-GIS building management strategy by organizing your building information content for the Techno-Z Building complex XIV (three floors)
  - Communicate the 3D model e.g. Desktop using (OGC City GML, ArcGIS Pro etc.), and/or using ArcGIS WebScenes and/or using VR (e.g. Minecraft)

The core focus of the project is to develop a sustainable Workflow and implementation for managing 3D building information supporting 3D maps for enhancing orientation. The students will develop skills for 3D data modelling and workflow management as well as for communicating with 3D maps and scenes,

SDI Topics

- SDI Conceptualisation
- Geospatial database management 2D & 3D
- Harmonisation and Standardisation for data Exchange (e.g. OGC GML, City GML,..)
- 3D Information (Map-) communication

Objectives

- To define 2D & 3D data models
- To (semi-)automate data integration and optimize data collection
To work with 3D Enterprise Geodatabases
To create applications communicating 2D and 3D Geodata

Proposed Workplan (details see introductions)
- Defining the content that shall be managed with your 3D buildings
- Define and prototype the (semi-)automatic/manual workflows for managing your 3D Building models
- Validation and communication
- Documentation

Deliverables
- Detailed description of the project: motivation, objectives, milestones, implementations
- Documentation on 2D & 3D Building conceptualization (UML)
- Documentation on 2D and 3D data models
- Documentation in data integration and collection strategies
- Validation results for Techno-Z Bauteil XIV
- Documentation and implementation of communication for the 3D Building model(s) created

Technologies/Skills used/developed:
- E.g. Visual Paradigm for UML
- Databases: ESRI, File-Geodatabase, ESRI Enterprise Geodatabase, Oracle Spatial, Postgres/PostGIS etc.
- Data Integration: ArcGIS Desktop, ArcGIS Pro, Safe FME, Geokettle, Autocad etc.
- Communication: ArcGIS Server, ArcGIS for Portal/ArcGIS Online, CityGML Viewer Minecraft (Education) VR
Integrated Project: SDI Services Implementation Winter term 2016
Topic 1: 3D – GIS Buildings for communication in 3D – maps
Group members: Reinel Bernhard and Schendl Gabriel

Initial data model

Final data model
Integrated Project: SDI Services Implementation Winter term 2016
Topic 1: 3D – GIS Buildings for communication in 3D – maps
Group members: Reinel Bernhard and Schendl Gabriel

Initial workflow

```
Preparation of CAD data
  Raw CAD data --> Acquisition of CAD data --> Examination, revision and enhancement --> Enhanced CAD data

Transformation with FME

Enhancement of GIS data
  Basic GIS data --> Geometric enhancement --> Semantic enhancement --> Extended GIS data

Definition of Communication
  Extended GIS data --> Define symbology --> Create Scene --> 3D scene --> Deploy 3D Web scene
  --> Create Map --> Map --> Deploy web map
```

Final workflow

```
Preparation of CAD data
  Raw CAD data --> Acquisition of CAD data --> Examination, revision and enhancement --> Extraction of features --> Addition of semantic data (Object Data) --> Enhanced CAD data

Transformation with FME (scale, reference, project)

Enhancement of GIS data
  Basic GIS data --> Semantic enhancement --> Extended GIS data
  --> Additional data

Definition of Communication
  Extended GIS data --> Define symbology --> Create Scene --> 3D scene --> Deploy 3D Web scene
  --> Create Map --> Map --> Deploy web map
```

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