Presentation and Evaluation of Inconsistencies in Multiply Represented 3D Building Models

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Abstract. Open architectures demand for a federation of data from different context providers, which nearly always will be inconsistent to a certain degree. We present an approach for the evaluation and presentation of inconsistencies in multiply represented 3D building models and provide means for the minimization of ground plan inconsistencies. The presented approaches are tested using differently detailed models from various sources.

Keywords: evaluation, inconsistency, 3D, city model, adjustment

1 Introduction

The increasing variety of applications which are based on spatial information resulted in a tremendously growing need for geospatial data. These demands are traditionally fulfilled by commercial vendors or governmental authorities, meanwhile also user-generated content like Open Street Map becomes more and more popular [1]. Since the data is captured by different providers, one object of the landscape was for example captured at different acquisition times, with different quality characteristics and different scales. Additionally it is stored in several databases and in different data models. This results in highly inconsistent data bases. The required integration of such multiple representations is a major research challenge in the field of GIS. Existing approaches mainly aim at the integration of 2D geospatial databases like street maps [2] or the evaluation of generalized 2D buildings [3]. However, we are aiming at the evaluation of inconsistencies in multiply represented 3D data as it is required for the processing of 3D building models used for applications in the context of urban planning, tourism, real estate presentation or personal navigation. Hence, these different purposes result in considerable differences with respect to the amount of detail or geometric accuracy for the available data.

Within the following section, our evaluation approach is presented based on different 3D building models covering the city of Stuttgart. Section 3 describes a first approach to minimize such detected inconsistencies. This is exemplarily implemented by an adjustment of 3D building models of relatively low geometric accuracy and small amount of detail to existing ground plans which were captured at a better geometric quality.

2 Inconsistency Evaluation

In this section, we describe our approach for the evaluation and presentation of inconsistencies between differently detailed 3D building models. This is done by comparing faces in both the reference and the input model that are equal in type. Relevant faces in the input model are projected into the coordinate system defined by the reference model's face and the intersection is computed. The ratio between the sum of all relevant faces' intersections and the reference face's area together with the mean angle and mean distance in between are mapped to the interval $[0;1]$ and used to colour the input face.

2.1 Test Data

In order to test the consistency evaluation approach, we use differently detailed data from four different sources. Thus, our test data consists of very detailed 3D building models from terrestrial data collection, an area covering data set from airborne photogrammetric measurements, a generalised city model derived from this area covering data set and extruded building outlines from Open Street Map.

The data set providing the highest level of detail was collected by order of the City Surveying Office of Stuttgart using terrestrial measurements. This data set features hand-crafted models of landmarks and photo textured facades of the main part of Stuttgart downtown. It was collected for selected buildings of Stuttgart aiming not only for an internal use in city planning scenarios, but also for visualization purposes as for example in Google Earth.

The next available level of detail is a city model, which is available area covering from airborne photogrammetric data collection. This medium detailed model was constructed combining existing ground plans from cadastral maps as provided by the City Surveying Office and roof shapes reconstructed from aerial images [4].

The third data source consists of 3D building models, which were derived from the aforementioned medium detailed data set by the generalization approach described in Kada [5]. This algorithm aims to reconstruct a simplified representation of the input building model by means of searching the main planes of the original model and subtending these planes in order to build a correct boundary representation. However, the models evolving from this approach differ from the original building models due to the averaging operation as it is implemented in the simplification process.

The finally used Open Street Map (OSM) data is expected to be the least detailed and least accurate source of information, caused by its acquisition method. Aiming to be a free and open source alternative to commercial map services, the complete Open Street Map consists of user-generated content. For its acquisition, volunteers mostly use consumer GPS receivers or copy points of interest, streets or building outlines from aerial photos released by their owners. While this map currently only contains 2D data, access to additional sensors and straightforward modeling tools may allow for user-generated 3D building models in the future. For selected building ground plans from this data set, the WGS84-coordinates were transformed to the German Gauß-Krüger coordinate system and the ground plans were extruded to the eaves height of the model taken from the official Stuttgart city model, resulting in 3D block models similar to those constructed with the approach described in [6].

2.2 Evaluation Approach

Our approach to evaluate the differences between two building models is based on the analysis of the respective faces as they are available in the so-called reference and the input model.
For every face in the usually highly detailed and accurate reference model, a local coordinate system is constructed. In the case of horizontal faces, this is the face's normal vector and its cross product with the x-axis of the model coordinate system, complemented to a right-hand-system. For all other faces, the z-axis is used instead of the x-axis.

Input model faces relevant for the comparison to the currently evaluated reference model face are compiled according to their type, where a distinction between wall and roof faces is made. Then, this set of faces is further downsized by comparing the normal vectors. However, instead of using an angular threshold, only faces with opposite direction to the reference face are removed as these are not likely to represent a similar building feature.

The relevant faces are then projected into the local coordinate system and the intersection of the actual reference face and the projected relevant face is computed using the General Polygon Clipper library [7]. If an intersection polygon exists, its area is computed. However, faces exceeding a distance threshold with their mean distance to the reference face are excluded. This is necessary, as for the final consistency value distance and angular inconsistencies will be merged with the areal differences. Faces exceeding the distance threshold are nevertheless regarded in the consistency computation by their missing area.

The final consistency value per face is computed as

$$c_r = \frac{\sum_i \left(1 - \frac{d_i}{d_{max}} - |\alpha_i|\right) \cdot A_i}{A_r} \qquad (1)$$

with d_i being the mean distance and α_i the mean angle between face i and the reference face, A_i being the area of the respective input face and A_r the area of the reference face.

This value in the interval $[0;1]$ may then be used in the visualization process. When used for example in $RGB = [1, c_r, c_r]$, the inconsistency of the input model to the current reference face is coloured from white (meaning maximum consistent) to red (maximum inconsistent). Results using the test data presented in the next section can be seen in the figures in section 2.3.

2.3 Results

As we consider the new Stuttgart city model the most accurate and detailed, we use the models stemming from this data source as the reference in our inconsistency evaluations.

In figure 1, the results for the Rosenstein museum models can be seen. As expected, the OSM model differs quite strongly from the reference model. However, the bigger differences in the longer walls in contrast to medium inconsistencies in the shorter sides reproduce quite well the shift of the complete building model, which can be seen when comparing the models with the naked eye. According to the OSM accuracy evaluation carried out by [8], differences in this range are to be expected. However, the areal differences used in the inconsistency evaluation may be too optimistic as the 3D wall faces evolve from the eaves heights of the Stuttgart city model and therefore are very similar to this model (see section 2.1).

In the generalized model, the strongly simplified roof structure shows the most distinct inconsistency to the reference model, with slight differences for the atrium and flat roof sides. The inconsistencies in the wall planes are mainly due to averaging during the generalization process and may therefore be minimized using the approach presented in chapter 3.

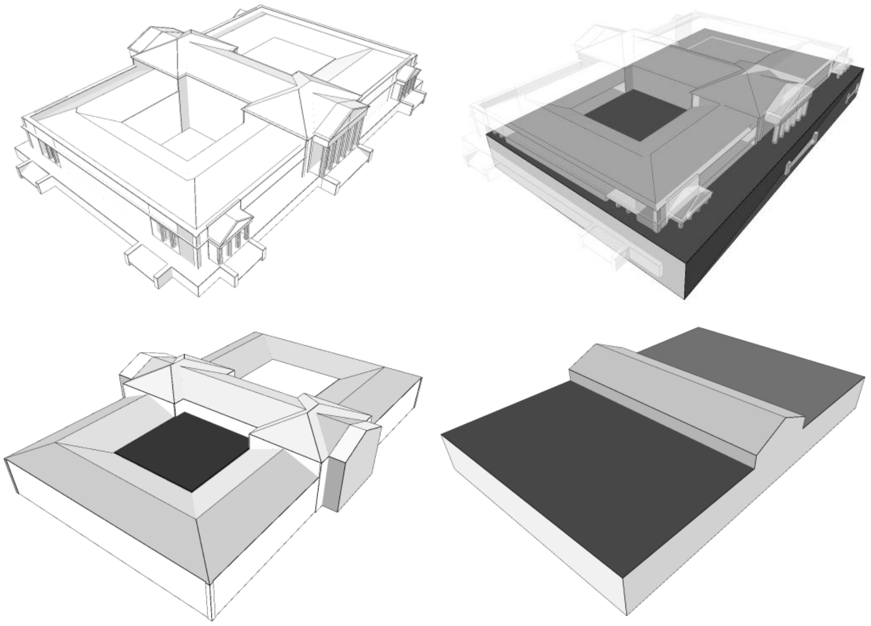

Figure 1. Clockwise: Inconsistencies of OSM-model, generalized model and city model from airborne data collection in comparison to the city model from terrestrial data collection (upper left), coloured according to section 2.2

The city model from airborne data collection, however, holds high consistency in the main wall planes. As both of these models are provided by the city surveying office, this is most likely due to the shared data basis and accurately measured ground plans. The slight inconsistencies in the roof planes stem mainly from differently modelled roof angles, whereas the atrium without a match in the model from airborne data acquisition is marked clearly visible.

Figure 1 therefore illustrates the level of detail improving from OSM to the city model from airborne data collection. While most of the inconsistencies evolve from these differing levels of detail, the OSM as well as the generalized model show additional ground plan inconsistencies, which may be minimized by the algorithm presented in the next chapter.

3 Minimization of Ground Plan Inconsistencies

In the following, we describe our approach for the adjustment of less detailed building models, which are used as input models to the ground plans of higher detailed and more accurate models, which for our algorithm provide the reference models. Its main idea is the description of the input model subject to movable wall planes. The model's 3D structure is represented by the decomposition into distance ratios with respect to the movable planes and fixed z-values. Using least squares adjustment, the movable wall planes are then adjusted to the major planes of the reference model, causing changes to the faces depending on them.

3.1 Model Analysis

In the first step, the faces of the less detailed input model are merged to planes using a distance and angle threshold. These planes are then classified according to their adjacency to the ground plan. Planes adjacent to the ground plan will be shifted in their normal direction during adjustment. To ensure for a minimization of the inconsistencies between lesser and higher detailed representation, the higher detailed reference model is analyzed in order to find appropriate shifting targets. Using the faces' areas as weights, these are constructed as the planes with maximum weight for a set of parallel faces below a given distance threshold.

In order to adjust the input planes to the major planes computed from the reference model, correspondences have to be established. Therefore, the major plane's weight is weighed against the distance between input plane and major plane in the form of a computed ratio. The respective input plane will be adjusted to the major plane with maximum ratio value.

In order to adjust the complete model to the major planes of the reference model, the remaining building structure has to be decomposed into parameters suitable to describe it subject to the wall planes adjacent to the ground plan. In the case of sloped roof planes, this is done by computing the distance ratios in the xy-plane shown in figure 2.

To avoid topological errors evolving for example from changes in the ridge and eave lines, the slope of these roof planes will be changed during adjustment, which is established by maintaining the z-value of the ridge line as well as the z-difference between ridge and eave line. For wall planes not adjacent to the ground plan, similar distance ratios are used, while flat roof planes are left unchanged.

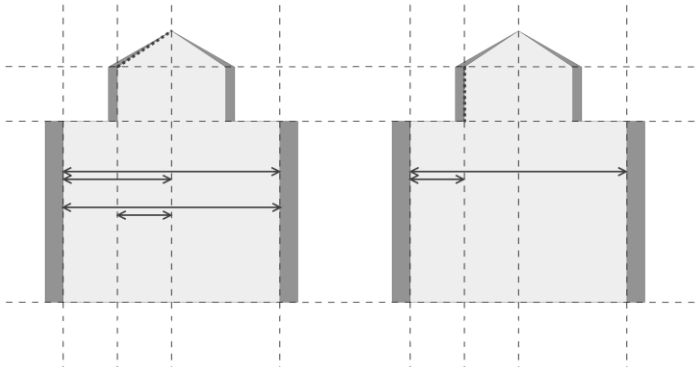

Figure 2. Distance ratios for planes not adjacent to ground plan (left: roof planes, right: wall planes; dark grey: situation before adjustment)

3.2 Least Squares Adjustment

The final model is obtained using least squares adjustment. In order to maintain characteristics like rectangularity and parallelism, the planes adjacent to the ground plan are merely shifted minimizing the distances to the resampled intersection lines between major planes and ground plane. This simplified 2D approach is applicable under the assumption of vertical wall planes. The reconstruction of the remaining 3D structure based on the distance ratio values computed before and the fixed height values completes the adjustment process.

3.3 Results

In figure 3, the result of the adjustment can be seen. Here, the city model from airborne photogrammetric acquisition was chosen as the reference model and the OSM respectively the generalized model were adjusted to it. Using the inconsistency evaluation approach from section 2, remarkable differences can be seen, particularly when using the OSM model. Besides minimized ground plan inconsistencies, the adjustment may also help in restoring symmetric structures which were affected by the generalization, as visible at the New Castle model's side wings.

The presented adjustment approach only works reliably, if all roof faces in the input model can be described by two wall faces similar in the projected direction and the associated parameters. Otherwise, these roof faces will not be adjusted at all which may lead to topological errors in the resulting model. Thus, highly detailed models like the ones taken directly from the two city models, may not serve as input models. In contrast, as they originate from official sources, they are rather considered as reference models for the adjustment.

As this approach reduces the 3D adjustment problem to two dimensions, it may also be used if the model considered more accurate only consists of a 2D ground plan, allowing for the adjustment of arbitrary building models to accurately measured ground plans.

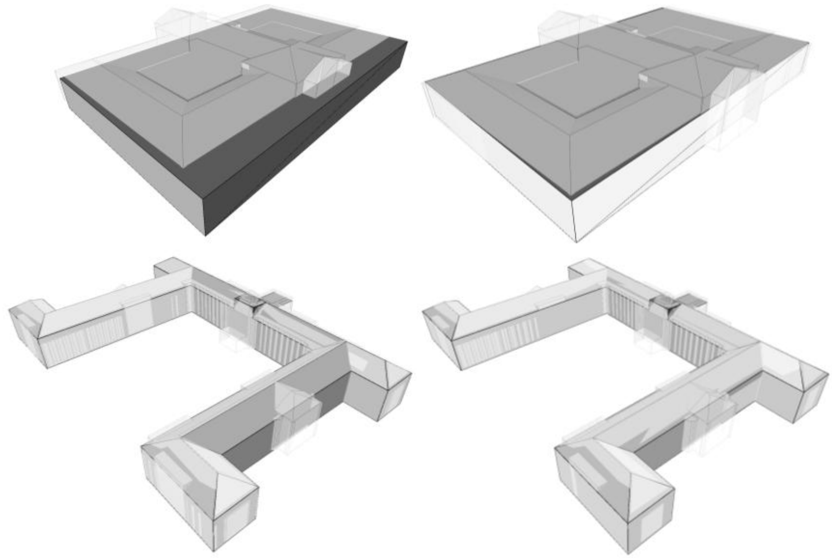

Figure 3. First row: Rosenstein OSM model before (left) and after (right) adjustment to city model from airborne data collection (transparent); second row: New Castle model generalized (left) and adjusted (right); coloured according to section 2.2

4 Conclusions and Outlook

Within the paper, an approach for the automatic detection of geometric inconsistencies between multiple representations of 3D city models is presented. Also based on such detected inconsistencies an adjustment process is used to combine these 3D data sources of different quality. One scenario for the usage of both approaches would be community-based change detection. As communities like Open Street Map rely on heavily distributed observations, their data is very likely more up-to-date than that from governmental or commercial sources. Detected inconsistencies could be used to initiate local revisions, while the version from the community data is visualized, adjusted to the ground plan in order to avoid errors related to building models in the vicinity.

Currently the analysis is based on a relatively simple distance measurement between the respective building parts. The implementation of a more advanced evaluation, which could also include a topological analysis and semantic attributes will be part of our future work.

Acknowledgements

The research described in this paper is founded by “Deutsche Forschungsgemeinschaft (DFG, German Research Foundation). It takes place within the Collaborative Research Centre No. 627 “NEXUS – SPATIAL WORLD MODELS FOR MOBILE CONTEXT-AWARE APPLICATIONS” at the Universitaet Stuttgart. The 3D building models are provided by Stadtmessungsamt Stuttgart, which is gratefully acknowledged. The Rosenstein Open Street Map ground plan was created by the users xylome2, BerndR, CvR and LayBack.

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