Depicting Settlement Development – Extraction and Visualization Workflow

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Abstract. Modeling of settlement development is a challenging task due to unavailability of historical datasets in vector format. Especially for older periods, only textual descriptions and no digital or analogue spatial datasets are available. For such historic periods, the modeling is difficult to be performed on a national scale due to the lack of automated procedures. Even for periods where historical maps are available, settlement development modeling is very time-consuming. A reason therefore is that paper deformation leads to inaccuracy of historic maps and the resulting problem of linking entities between different datasets and periods. In this paper, a novel approach is proposed. Based on vector datasets containing information, such as the construction age of current buildings, the historic settlement development is reconstructed. The increased availability of such vector datasets, including cadastral data, enables automated and 'cartographically correct' depiction of settlement development on a national scale.

Keywords: settlement development, 3D visualization

1. Introduction

In many countries the interest in inward urban planning became a very important topic over the last years. With the help of settlement development modeling, one can compare the situation before and after the application of planning policies, and calculate the area of occupied land in different periods of time (Wissen Hayek et al. 2011).

The biggest challenge in such modeling is to aggregate building footprints in a way that the aggregation is uniform for the whole area and does not contain smooth lines created by buffering. Before starting with the aggregation, building footprints must be available. There are two main possibilities: one can extract the footprints from scanned historical maps or one may take the current digital building footprint data from the cadastral survey. There were many attempts to extract building footprints and other valuable information from scanned historical maps, however, it requires time-consuming manual pre- and post-processing (Arteaga 2013, Chiang et al. 2011, Rickenbacher 2013). The main problem of many historical maps in Switzerland is that buildings have exactly the same color value as labels and road network, which makes the separation of them rather difficult. Moreover, the geo-referencing of maps is not accurate enough for such a task, due to the paper distortion (Iosifescu et al. 2013). Therefore, the current building footprints could be taken, making it necessary to join building footprints with data tables containing additional information, such as the construction year of buildings. These data contain coordinates of the building entrance and can be represented as a point dataset. However, in many cases the points are not within the building footprint due to different accuracy of the data collection, or typographical mistakes, making it necessary to apply error aware matching strategies. Therefore, a workflow to assign the point dataset to building footprints is proposed and validated in this project. The idea is to use all the available attributes for the combination "building footprint–lot–point data". Different municipalities are responsible for the management of the point dataset, and not all of the attributes are mandatory, making the data inconsistent. Consequently, the data are matched with different strategies, such as the minimum-cost and the nearest neighbor methods, depending on the available attributes, where in the end the best matching is selected.

Existing methods of settlement area depiction have several limitations regarding the purpose of this project. Many of them focus only on the aggregation of building footprints or building point data without taking into account the cadastral lots, whereas the idea here is to simulate a settlement with its allotments and leisure zones, but not just a built-up area. Thus, two workflows for depiction of settlement development are proposed, one includes the cadastral lots and the other one simulates lots based on the road network, grid and the land use information.

Lately, various datasets containing the information about building construction year started to be available in different countries, making it possible to assume that the proposed workflows described in this paper can be also used in other projects.

Mostly, such data are visualized by coloring individual buildings, depending on their period of construction. Such maps as "Brooklyn's past and present" by Rhiel (2013) and "Buildings in the Netherlands, shaded according to year of construction" by Spaan and Waag Society (2014) are good examples of such visualizations.

2. Related Work

Settlements are defined in different ways, though most of the definitions agree on including green zones and road networks in the settlement. This is a crucial definition in this project, making it necessary to model not only the built-up areas, but also surfaces, which cannot be used for construction anymore, such as streets, runways of airports and cemeteries, and also the non-built-up surfaces inside and around of the built-up areas.

In the "Schweizer Arealstatistik" (English: Swiss land use statistics) (2011), settlement is defined as a surface, which is characterized mainly by working, living, recreation and transport, where objects, such as parks, cemeteries, streets, etc. are included in the settlement. Similar definition can be found in Esnard and Yang (2002) where undeveloped land, which is completely surrounded by developed areas (e.g. cemeteries, parks, etc.), is a part of the settlement. Chaudhry and Mackaness (2008) highlight that a settlement is not just a group of buildings, but a surface containing transportation networks, green spaces and rivers. Meinel et al. (2014) have created a detailed schema of the land use, where different types of sport and free time facilities, industrial zones and allotments are included in the settlement.

When the buildings are available as points or footprints, they must be aggregated in order to create a built-up surface. Further, this surface must be complemented with transportation areas, green spaces and recreation zones.

Approaches for the aggregation, such as grids (Office for National Statistics UK 2013, Harding et al. 2013), triangulation (Bundesamt für Statistik BFS 2007) and buffering (Arealstatistik Schweiz 2011) create uniform results for the whole area, which has the highest priority if the aggregation is used for statistics. Some of the methods use fixed values for buffering (Bundesamt für Statistik BFS 2007, Arealstatistik Schweiz 2011) and some use additional indices, such as ‘citiness’, which is a coefficient integrating area of the building, a distance to each footprint and the total area in the neighborhood (Chaudhry & Mackaness 2008).

However, smooth lines created by buffering do not represent built-up areas or settlement in a way, which is ‘cartographically correct’, similar problem have borders created by grids and triangulation *(Figure 1)*. It is important to mention that the workflow introduced by The Swiss Federal Statistical Office (Bundesamt für Statistik BFS 2007) further corrects the created areas by the intersection with the prime surfaces dataset; however, it does not remove the smooth lines, introduced by buffering.

a) jagged appearance of grid aggregation (Harding et al. 2013)

b) smooth lines (Bundesamt für Statistik BFS 2007)

c) usage of angular buffer (Chaudhry & Mackaness 2005)

Figure 1. Comparison of different aggregation approaches.

An approach to solve this problem is proposed by Chaudhry and Mackaness (2005) where the authors have applied an angular buffer and the Douglas and Peucker algorithm for further generalization. However, this approach does not take into account the road network, creating irregular partial overlapping with the streets. This task was partially solved by the Esri algorithm "Delineate Built-Up Areas" (ArcGIS Resources 2014a). The algorithm is created in order to automatically depict built-up areas in different scales, e.g. buildings and aggregated surfaces, and it takes into account road networks, water bodies, and any other delineation datasets, which one wishes to use. The algorithm connects edges of buildings based on the user-defined grouping distance, which sometimes leads to unwanted visual results despite logical definition (*Figure* 2).

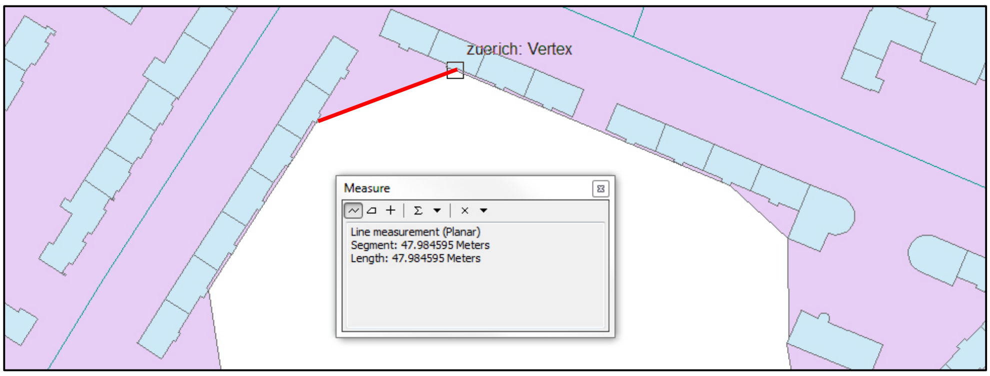

Figure 2. Aggregation with Esri's "Delineate Built-Up Areas" algorithm. The measured distance is marked with red (47.98 m). The user-defined grouping distance is 50 m.

3. Data

Several official datasets are used in this project. An overview is given in *Table 1*. The datasets swissBOUNDARIES3D and swissTLM3D are managed by the Federal Office of Topography swisstopo[i]. The swissBOUNDARIES3D dataset contains the administrative units of Switzerland and Liechtenstein. The swissTLM3D dataset is a large scale Topographical Landscape Model of Switzerland, which stores natural and artificial landscape features as 3D vectors.

Datasets	Geometry Type	Attributes used for matching
swissBOUNDARIES3D[ii]	polygon	FOSNR (municipality number)
swissTLM3D Buildings[iii]	polygon	-
swissTLM3D Roads and Tracks	line	-
swissTLM3D Land cover	polygon	-
swissTLM3D Land use	polygon	-
Historic Municipality Mutations[iv]	-	All historic mutations of FOSNR
Register of Buildings and Dwellings (RBD) [v]	point (integer coordinates)	EGID (a unique id for each building) FOSNR LOTNR (a number identifying a lot of a building) Footprint area (only ~40% of the data)
Cadastral Survey Building Footprints[vi]	polygon	EGID (not available in large parts of Switzerland) FOSNR Date of change
Cadastral Survey Lots	polygon	LOTNR FOSNR Date of change
Cadastral Survey Building Entrances	point	EGID (not available in parts of Switzerland) FOSNR

Table 1. Overview of the datasets used in the project.

The Swiss Federal Register of Buildings and Dwellings (RBD) is a point dataset collected by the Swiss Federal Statistical Office based on the census of the year 2000. It includes numerous attributes, such as building construction year, construction period and footprint area. Every building in the RBD has a unique id (EGID). The EGID attribute is available in the data model of the cadastral building footprint and building entrance datasets. However, due to missing EGID values in the cadastral data only 63% of the RBD buildings can be matched with the help of the EGID. In the process of matching the RBD dataset with cadastral building footprint, inconsistencies resulting from different interpretations of the semantics of buildings as well as typographic errors could be detected.

The cadastral survey data include building footprints, lots and building entrances. Unfortunately, not all of the cadastral data are available digitally. There are 26 cantons in Switzerland and 10 of them had a full digital coverage at the end of 2013, and 12 cantons had a coverage of 90 %. Depending on the canton the coverage varies between 100% and 42% (Amtliche Vermessung Schweiz 2013).

4. Methods

4.1 Join of the RBD point data and cadastral survey polygon data

The RBD points have to be matched to the building footprints. The straightforward way is to use a spatial join. However, this method does not utilize the available information stored in the attributes, which would help to increase the confidence in matches and to resolve inconsistencies.

4.1.1 Preprocessing

Municipalities are identified with the help of the municipality number id (FOSNR). Due to fusion of municipalities the FOSNRs changes. This leads to a problem when linking entities with the help of FOSNR over different datasets with different age. Therefore, all datasets must be updated to the same timestamp of the municipalities' borders.

Two datasets are used for this purpose: the swissBOUNDARIES3D and the list of Historic Municipality Mutations. The swissBOUNDARIES3D dataset is used in order to update FOSNR of the cadastral survey geometries based on their spatial relationship to municipalities. The Historic Municipality Mutations dataset is needed, because it includes regularly updated information of all FOSNR mutations since 1960.

The RBD points also contain the attribute of the municipality number, but not all the RBD points are within the geometry of the correct municipality according to the FOSNR. As RBD data are collected on the municipality level, it is assumed that the FOSNR is correct, whereas the coordinates may contain errors, which have displaced the position of the points outside the municipality borders.

Moreover, the following steps are performed in the preprocessing part:

- Removal of overlapping lots polygons (large lots of cadastral zones or districts inside the municipalities) with an area greater as 10 km^2;
- Removal of duplicated buildings with an overlap area of more than 95% (depending on the attribute of the date of change the older polygon is removed, with the same date of change a polygon with the lower id is removed);
- Removal of all the buildings with a bounding box area greater than 0.1 km^2 (land cover polygons classified as buildings);
- Unification of the different format of the LOTNR in the cadastral data and in the RBD data.

As not all the buildings from cadastral survey are digitally available, it was decided to add the missing building footprints from the swissTLM3D dataset, even though it is less precise due to surveying methods used.

4.1.2 Matching

The following matching strategies are applied to the data; they are listed from the best to the worst, meaning that for each RBD point the highest ranked matching is selected:

1. Building entrance EGID
2. Building EGID
3. Minimum-cost matching
4. LOTNR
5. Error aware building entrance EGID
6. Error aware building EGID
7. Error aware Minimum-cost matching
8. Error aware LOTNR
9. Spatial Join

For each matching strategy, different levels of quality depending on the availability of typographic errors are defined, which eventually allows to choose the best matching for each RBD point.

In other words, the idea is to match RBD data with the cadastral data based on the EGID number. If no EGID number is available, the buildings and RBD points, which are within the same cadastral lot, are matched together. However, as it is described in *Section 4.1.1* the coordinates of the RBD data are not free of errors. This fact must be taken into account by the matching strategy. A solution for such case is an error tolerant minimum-cost matching. For this matching, all RBD points with the same EGID need to be within a building. Moreover, the RBD data point needs to be within the same building as the building entrance point.

In order to match RBD points and buildings both datasets are grouped according to their LOTNR. If the number of buildings equals the number of RBD points, the matching is done by minimum-cost. The costs in our case are the distance between the building and the RBD point. Each building should be assigned to exactly one RBD data point so that the total distance between RBD points and buildings is minimized (*Figure* 3).

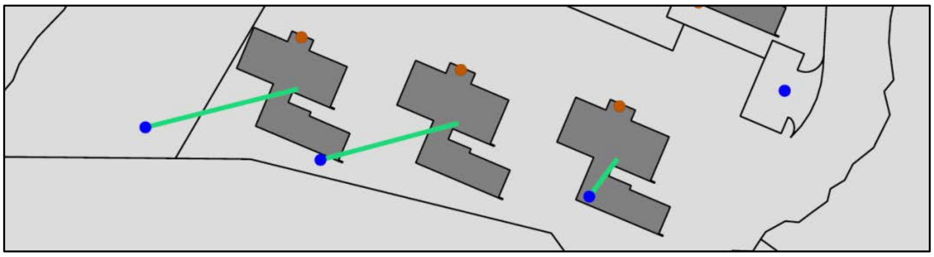

Figure 3. Minimum-cost matching strategy. Blue points are the RBD dataset, orange points are Cadastral Survey Building Entrances, and green lines show to which building the RBD points correspond.

When no EGID is available, the matching is performed by LOTNR, however, there are the following difficulties:

- Multiple buildings can be located on one cadastral lot. If RBD points are not within these buildings it is not easy to match the points with the correct building;
- The LOTNR is not unique per municipality, this difficulty is solved by assigning each RBD point to the nearest cadastral lot with the same LOTNR;
- The definition of a building differs for RBD dataset and the cadastral survey, therefore, buildings with a footprint less than 20 m^2 were removed from the cadastral data;
- There is only a spatial relationship between buildings and cadastral lots; however, some buildings overlap several cadastral lots. For such cases it is decided that at least 80 % of a building need to be within the lot.

It is assumed that if a match is found based on the EGID, it is a valid match, which is not caused by errors in the coordinates. Additionally, it is assumed that the coordinates in the cadastral data can be trusted. If inconsistencies between the RBD and cadastral data and the attributes EGID, LOTNR or coordinates can be detected, or no direct matching is possible, error aware matching strategies are applied.

Typographic errors are detected with the Damerau-Levenshtein distance (Damerau 1964), which counts the number of operations needed to transform one string to the other. Supported operations are the insertion of a character at any position, the deletion of a character, substitution with another one and transposition of two adjacent characters. Damerau-Levenshtein distances of 1 for attributes with a length of at least 3 characters are considered as a typographic error.

The error aware matching strategies try to match points to building footprints when inconsistencies make a direct match impossible. For example, if a RBD point is located on a lot with a deviating LOTNR. This can happen due to a typographic error in the LOTNR or an error in the coordinates of the RBD point. An example for the latter case is shown in *Figure* 4.

a) coordinate 6**32**828, 208659 of RBD point

b) coordinate 6**23**828, 208659 inside a building with the same LOTNR as RBD point

Figure 4. An example of typographic error in the coordinates, detected by the Damerau-Levenshtein distance.

The last strategy is to match the RBD points to the nearest building within 5 meters of a RBD point.

The attribute of the footprint area is not used for the matching, but for the validation. In this analysis the area of the buildings from the cadastral survey is compared to the sum of all area attributes of the matched RBD points.

After this step the data can already be used for visualization of the buildings' age.

4.2 Age of buildings instead of settlement development

As mentioned before, the information about destroyed buildings is not reflected in the data as it would be on historical maps. For this reason, additional analysis must be done, in order to map the settlement development and not the age of a building. This means that the possibly earliest occupation of the land must be detected.

In *Figure* 5 a comparison of a historical map of the year 1946 with the current situation can be seen. Many buildings, which have existed in 1946, are not reflected in the current dataset (only the brown and dark orange buildings are correctly depicted). One approach to overcome this problem is a ‘correction’ of the period of construction in the case, when all the surrounding buildings have an earlier period of construction. To minimize the risk of wrong assignments, only the difference of two or more time periods should be corrected. This means that in the case of period 1961–1980, which is marked with a red rectangular in *Figure* 5, the year of construction should be changed to 1920–1945. No changes would be done if the surrounding buildings would have the next period of construction, e.g. 1946–1960. Unfortunately, this approach is not robust and requires more input information, such as spatial documents from the planning offices, which show demolition zones or zones of rebuilding, e.g. Toni-Areal in Zurich (Toni-Areal 2013).

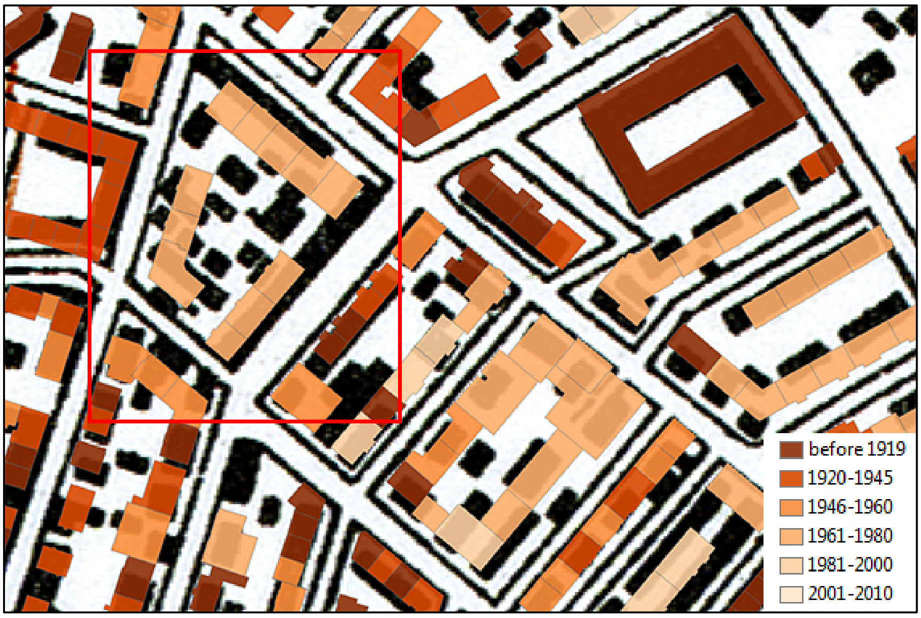

Figure 5. Comparison of a historical map and the current situation. Siegfried map serves as the background (317, 1:25 000, year 1946).

4.3 Aggregation of the cadastral lots

Not all RBD points have the year of construction as an attribute (only 45.33%), however, the period of construction is available in 96.34% of the cases. The official periods, used by the Swiss Federal Statistical Office are the following: before 1919, 1920-1945, 1946-1960, 1961-1970, 1971-1980, and then every five years till 2010. In this project, it is decided to keep the first three periods and to combine the rest in periods of 20 years (1961-1980, 1981-2000) and 10 years (2001-2010). As no other time periods than those defined by the Swiss Federal Statistical Office are available, it is impossible to validate the results against the datasets created manually by the Historical Dictionary of Switzerland[vii] based on historical maps. These datasets are available in digital form for the biggest cities in Switzerland and have time periods of 30 years starting with 'before 1850'.

4.3.1 Workflow based on the cadastral lots

In order to create a settlement development map, the simplified cadastral lots attributed with the period of construction have to be separated from each other in a way that every following time period contains the previous periods. The same procedure is performed for the buildings.

After a long search for the best aggregation function, it is decided to use the Esri algorithm "Aggregate Polygons" (ArcGIS Resources 2014b). This algorithm connects the edges of the cadastral lots within predefined distance, keeping the output features orthogonally shaped.

First, the percentage of buildings' area to the area of corresponding cadastral lot is calculated. If the value is lower than 10 %, the cadastral lot is deleted. This is necessary in order to remove polygons, which are big in size and contain few buildings. For these buildings, the lots have to be simulated. Therefore, a grid of 50m x 50m is created, and with a spatial join the cells, which contain these buildings, are defined. The remaining cadastral lots and the created grid cells containing the buildings are aggregated, depending on their period of construction, with a threshold distance equal to 30 m. This value is chosen empirically, based on visual analysis. It is valid for both rural and urban settlements.

Further, the road network is cut from the resulting aggregated polygons in order to make the visualization look closer to reality. For this purpose, first, dead-end streets should be removed from the road network dataset. In this project, this is done with the Esri algorithm "Cul-De-Sac Masks" (ArcGIS Resources 2014c). Many streets consist of several fragments, making it necessary to repeat this operation several times. For instance, in the municipality of Bern the dead-end streets are removed after 7 iterations. It is important to include the border of the municipality in the road network, in case when the processing is done by one municipality after another. Otherwise, highways and other roads crossing many municipalities will be attributed as dead-end streets and removed from the dataset.

Further, streets must be buffered according to their official width, and tunnels must be removed from this dataset. It is obvious that the usage of a current road network dataset does not represent the situation, for example, of the beginning of the 20th century, however, it seems to be a good tradeoff between the achieved result (*Chapter* 5) and time-consuming road network extraction from historical maps.

After the dead-end streets are erased, a set of correction algorithms is applied in order to remove the artifacts. Polygons without buildings and polygons having high values for the perimeter and small for the area (extremely long and thin polygons) are removed. Moreover, holes in the polygons less than 15 m^2 are closed.

The grid cells containing detached buildings, which are further than 30 m from other cells or cadastral lots, are cut with the road network as well, decreasing the jagged appearance of grid aggregation. Moreover, the land cover classes, such as different types of forests, water bodies, glaciers, and land use classes, such as cemeteries, parks, wine yards, etc. of swissTLM3D dataset are cut from the result.

4.3.2 Workflow based on the simulated lots

As the workflow based on the cadastral lots is very simple, it is necessary to be able to simulate the lots for regions, where cadastral data are not digitally available.

In this project, there were many attempts to aggregate the buildings in a way, which appears 'cartographically correct'. It turned out that the most visually appealing result is to cut the resulting aggregated polygons by road network, as it is described in *Subsection* 4.3.1. Therefore, it is decided to start with the simulation of lots by erasing the road network from the municipality polygon. In this way we have obtained rather small polygons in the center of the city and bigger polygons on the outskirts and in the rural areas. This tendency corresponds to the structure of the cadastral lots, however, with a smaller level of detail.

After this step, as in case with cadastral lots, the total area of the buildings within each polygon is calculated. The polygons with the area of buildings less than 10 % of the area of the polygon are replaced with the 50m x 50m grid cells containing the buildings. Further, the resulting polygons are united *(Figure 6)*.

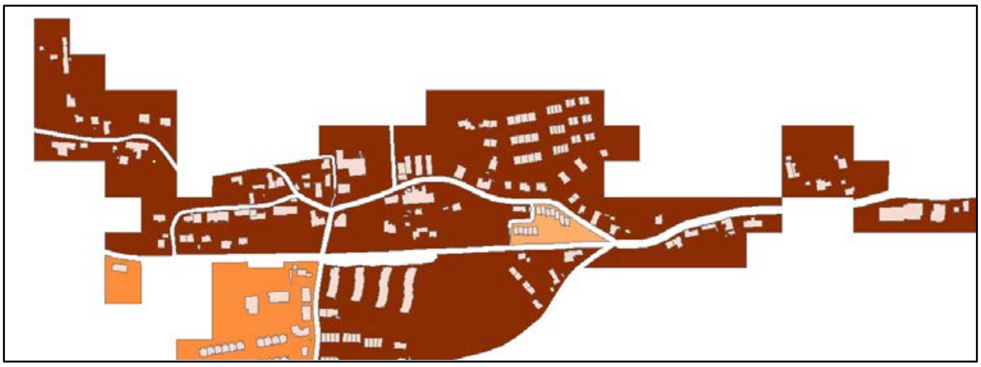

Figure 6. An example of the grid and simulated lots combination.

The aggregation in this workflow is not necessary, because the level of detail in the simulated lots is not as high as for the cadastral lots. It is also not necessary to perform such steps as the removal of the polygons, having high perimeter values and small area, due to the absence of the artifacts generated in the first workflow.

Further, the land cover and land use classes are cut from the resulting polygons.

After simulation of the lots, it is necessary to assign them a construction period. In the case of cadastral lots, every lot has its own period of construction, but for the simulated lots it is decided to check the period of construction of all the buildings within each lot and to assign the earliest period of construction to the lots.

5. Results

As mentioned before, the statistical comparison against the datasets created for Historical Dictionary of Switzerland is not possible; therefore, visual comparison is done between the results and the buildings attributed with the year of construction. Moreover, the results of the two workflows are compared with each other. In *Figure 7* one can see that the usage of the cadastral lots offers a greater level of detail in comparison to the simulated lots. In case the detailed information is not necessary, this property can also be an advantage, due to the limited amount of artifacts.

a) result of the modelling based on the cadastral lots

b) result of the modelling based on the simulated lots

c) 50 % transparency of the result a) over the inverted colors of the result b) with a 1 mm shift. Gray color corresponds to no changes

Figure 7. Comparison between the results of the two workflows.

The final results are a part of the new version of the “Atlas of Switzerland”. The atlas supports querying of layers and combination with different background maps, such as historical maps, satellite image or shaded relief (*Figure 8*).

Figure 8. Resulting settlement development structure of Bern. The background image is Swissimage 50[viii].

As it is discussed in *Chapter* 2, a road network belongs to a settlement, but it is decided to use this information as additional layer without integrating it in the settlement polygons. Moreover, this map provides different classes of land use and land cover as additional layers, which can be turned on and off. The transparency of each layer can be changed, making it possible for users to estimate if one or another land use class has changed its shape significantly since the first depicted period of time.

Related themes are defined within the atlas, making it possible for the user to see, which map should be combined with the existing one. This can be helpful for clarifying the reasons of settlement development, such as a construction of a tunnel, new road or industrialization.

The new version of the "Atlas of Switzerland" is based on a virtual globe, making it possible to visualize every map in 3D (*Figure* 9). This is a great advantage for a settlement development map, where the relief plays a crucial role in the evolution of a settlement.

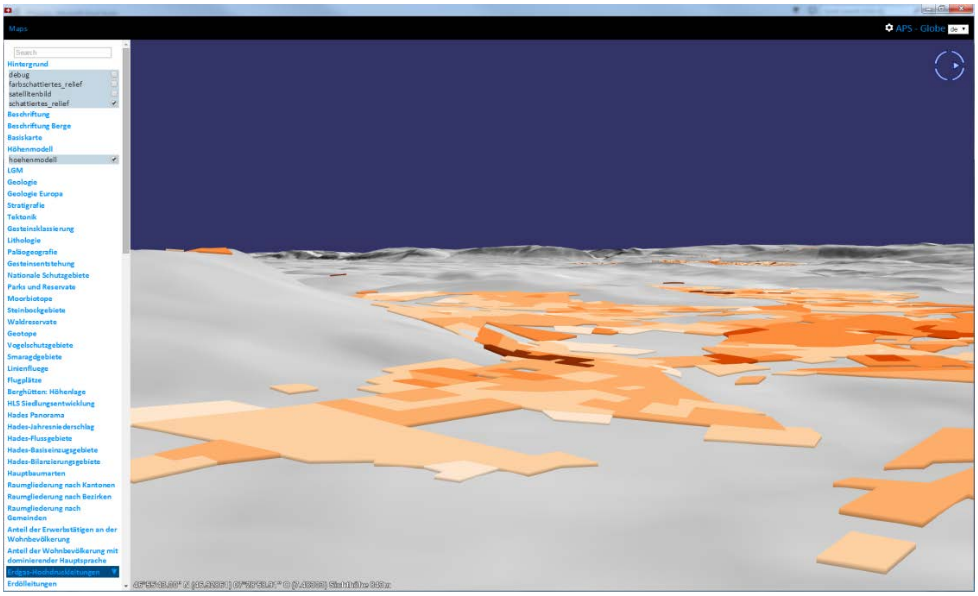

Figure 9. Extruded shapes of settlement development in the region of Bern. Atlas of Switzerland prototype with a tentative graphical user interface.

6. Conclusion

The paper proposes a methodology how different datasets can be matched together based on their spatial relation and common attributes. It also gives an overview of approaches used for built-up areas delineation. Finally, it suggests the usage of cadastral lots and simulated lots for settlement development. The reason is that a lot includes an area around a building, which should be modeled together with the building itself. Cadastral lots serve as good delineation borders, not letting the settlement polygon to spread irregularly over highways, forests or other zones, whereas, the simulated lots are modelled based on these elements.

The information about destroyed buildings is not reflected in the data. This requires additional analysis in order to 'correct' the year of construction attribute of the input data. Another possibility is to use more input information, which can be available in planning or architecture offices. Such data may include zones of rebuilding or demolition.

Similar problems exist for the land use classes. There is data available for earlier periods, but not for the situation hundred years ago. The solution would be to extract this information from historical maps based on the spatial patterns of the land use classes.

The fact that not only in Switzerland such data are available makes it possible to assume that the proposed workflows can also be applied in other countries.

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[v] http://www.bfs.admin.ch/bfs/portal/en/index/themen/00/05/blank/01/03.html

[vi] http://www.cadastre.ch/internet/cadastre/de/home.html

[vii] http://www.hls-dhs-dss.ch/d/english

[viii] http://www.swisstopo.admin.ch/internet/swisstopo/en/home/products/images/ortho/swissimage.html