AUTOMATIC CALCULATION OF BUILDING VOLUMES FOR AN AREA-WIDE DETERMINATION OF HEAT REQUIREMENTS

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KEY WORDS: Laser Scanning, Building Extraction, DSM/DTM, Human Settlement, Classification

ABSTRACT:

Power authorities are highly interested in numbers that indicate the energy requirements and especially the heat requirements on a local, regional and country-wide level. Existing methods for estimating those requirements heavily rely on local sampling methods, the use of estimates and models. In order to determine more accurate base information, we are using laser scanning in this project as a base data acquisition method. This is due to the fact that laser scanning potentially allows an area-wide data capture, and also has a high potential of automated data analysis and interpretation. For the models that calculate the heat requirements, different types of prior information are necessary: the volume of individual buildings, their individual heat requirement, as well as the distribution of the buildings in order to determine clusters that can potentially be adequately supplied by one type of heating system. In this paper, we give a brief introduction into the topic and show our first results regarding the automatic determination of building volumes.

1. INTRODUCTION

Our work is part of an ongoing project on pluralistic heat supply ("Pluralistische Wärmeversorgung") which is funded by the AGFW (Arbeitsgemeinschaft Fernwärme, e.V.). AGFW is an organization of energy and service providers which are engaged in local and district heating.

One of the goals of this project is to detect locations where local and district heating can compete with traditional heating by electricity, gas or oil. For that purpose, model calculations are performed which in turn need highly detailed information on the heating demand. However, existing information is often out of date or not available on an area-wide basis.

Thus, we aim to derive this information from different data sources. Since the heating demand of buildings is correlated with the building volume, our first goal is to extract building volumes. In a second step, these can be combined with additional information such as specific heat coefficients which depend on the building type and year of construction.

There has been a huge amount of research in the field of automatic extraction and reconstruction of man-made objects, including buildings, see e.g. (Baltsavias et al. 2001). For example, Weidner (1997) uses laser scan data to extract buildings. Using a segmentation of a normalized digital surface model (DSM) the locations of buildings are detected. From this, the ground plans are reconstructed. Brenner (2000) describes the reconstruction of 3D-buildings from laser scan data and ground plans, leading to detailed roof topologies. However, in our case a detailed reconstruction of the building's geometry seems not to be necessary, as we are interested mainly in the volume and not in the exact shape. Other geometrical features such as roof area and slope might be interesting at a later stage, for example to derive assumptions about the year of construction.

DSMs from laser scanning are well suited to derive building volumes as they generally preserve jump edges quite well and are easier to use in automated methods as compared e.g. to aerial images. There are many different algorithms to derive a DTM from a given DSM. For example, Masaharu and Ohtsubo (2002) divide the area into small tiles and select the lowest points. In a further step, it is verified if these represent the terrain. Then the initial DTM is created. At the moment this method can only be used in flat terrain. Briese et al. (2002) use robust methods to classify the original points into terrain and off-terrain points.

In order to obtain a precise definition of the terrain, additional data sources can be integrated. For our studies, we explored the use of ATKIS and ALK datasets. ATKIS is the Authoritative Topographic Cartographic Information System in Germany (ATKIS, 2003). It contains information on settlements, roads, railways, vegetation, waterways, and more. However, for our studies we only used the roads layer. ALK is the digital cadastral map containing information on parcels and buildings (AdV, 2003). Again, we used only a small part of the available information, namely the ground plans of buildings. Figure 1 shows ATKIS and ALK data for a part of our test area.

2. ENERGY AND HEAT REQUIREMENTS

For the planning of local and district heating it is necessary to know the location and spatial distribution of consumers. Therefore, highly detailed information about heating demands is needed (Blesl, 2002).

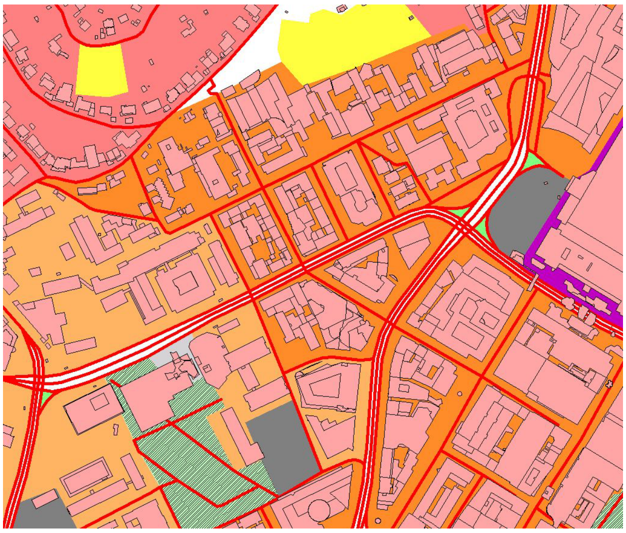

Figure 1: Vector data sets used in this study: ALK (building ground plans) and ATKIS (street axes, in red).

In the past, different methods have been developed to determine the heat demand. A description of the most important methods can be found in (Roth, 1980).

There are methods which rely on the mean energy demand of standard building types, e.g. one family house or row house. To use such a method, buildings are classified using the area and the number of floors or the volume of a building. With laser scanning, this can be done automatically. Furthermore, laser scanning allows an area-wide data capture and it is easy to keep the data up to date.

Although it is possible to obtain the area and the volume of a building from laser scanning data, it is of course not probable to determine the age of buildings or the kind of heat insulation. Therefore, the volume information has to be adequately combined with additional information in order to get an estimate about the heating demand of that building. Possible additional data sources are: age of building, date of renovation, type of building, etc. Thus the buildings can be classified into certain types, that – in turn – can be assigned a given heating demand.

3. DETERMINATION OF BUILDING VOLUMES

In the first step of the project we are investigating different approaches for the capture of individual building volumes:

- methods that only use laser scanner data
- methods which use topographic information (esp. streets from ATKIS) in order to determine the DTM
- methods using building ground plans as prior information (i.e. data from ALK).

The approaches are shown here in the order of increasing requirements regarding prior information. Whereas the first approach tries to operate solely on laser scanner data, the second needs ATKIS datasets, which are collected in Germany by the mapping authorities in each federal state. Since the product is standardized and can be obtained nationwide from the Federal Agency for Cartography and Geodesy (BKG), however, it is reasonable to assume it can be incorporated into an automatic approach. Furthermore, since we are using only a subset of the ATKIS information, namely street axes, one could alternatively rely on GDF data (GDF 3.0, 1995), which is collected by private companies for the car navigation industries and meanwhile covers large parts of Europe and North America.

Finally, the third approach uses ALK data, which contains a huge amount of information, among them the ground plans of buildings. Even though it would be not easy to gather this information for entire Germany from a practical and financial viewpoint, it is nevertheless sensible to consider ALK as prior information, since the power authorities often are in possession of ALK data anyways.

All of our approaches work basically by determining a DTM from the given digital surface model DSM. By subtracting the DTM from the DSM, a normalized DSM is obtained, from which the required objects and their volumes can be extracted.

As our main data source we use a DSM from laser scanning for all of our approaches. Depending on the method, we use either regularized data, sampled to a 1 m grid, or irregular data as delivered by the scanning company. The laser scanning datasets typically have an accuracy of 10 – 20 cm in height and 50 – 100 cm in position. Our test area covers part of the city of Stuttgart, Germany.

3.1 Volume Determination Based on Morphologic Operators

We have tested different approaches regarding the determination of building volumes from the DSM without any prior information. Our tests have shown that methods relying on the detection of jumps in height or slope, i.e. derivative and curvature based methods, do not perform very well. The reason for this is that on the one hand hilly terrain causes large values, whereas on the other end, edges at building borders frequently lead to too small values due to close or overlapping vegetation.

We have therefore used a morphological filter known from digital image processing (Gonzales, Woods, 1993). It is derived from morphological operations on binary images, involving a structure element s which is a set of coordinate pairs. For a symmetric structure element, the *erosion* of an image I with structure element s is

$$(I-s)(r,c) := \begin{cases} 1 & \text{if } \forall (i,j)\in s : I(r+i,c+j)=1 \\ 0 & \text{else} \end{cases}$$

whereas the *dilation* is defined as

$$(I+s)(r,c) := \begin{cases} 1 & \text{if } \exists (i,j)\in s : I(r+i,c+j)=1 \\ 0 & \text{else} \end{cases}.$$

The generalization to grey value images is straightforward and can be given as

$$(I-s)(r,c) := \min_{(i,j)\in s}\{I(r+i,c+j)\}, \text{ and}$$

$$(I+s)(r,c) := \max_{(i,j)\in s}\{I(r+i,c+j)\}$$

for the erosion and dilation, respectively. As a regularly rastered DSM can be considered as a grey value image, these operations can be directly applied to regularized DSM's from laser scanning.

Erosion and dilation are often used in sequence, and are called *opening* and *closing*, depending on their order. Opening is an erosion followed by a dilation:

$$(I\circ s) := (I-s)+s\,.$$

Applying the operators in sequence ensures that structures in the image which do not interfere with the structure element S are mostly unaffected.

Figure 2 shows the original DSM, as obtained from interpolating the laser scan point cloud by a regular 1 m^2 grid. Greenish values are low, reddish values high altitudes. Figure 3 and Figure 4 show the same DSM after application of the erosion and the opening. The artefacts of the circular mask can be seen clearly in those images. Finally, Figure 5 shows the final normalized DSM. One can see that the ground level is near zero even in formerly hilly terrain and the buildings can be identified quite well.

Of course, one has also to note that choosing the size of the structure element is generally nontrivial. It should be larger than the building diameters. However, in densely built-up areas, this might be very large, causing artefacts in hilly terrain. Therefore, if additional information is available on points lying on the terrain, this should be included, as shown in the next section.

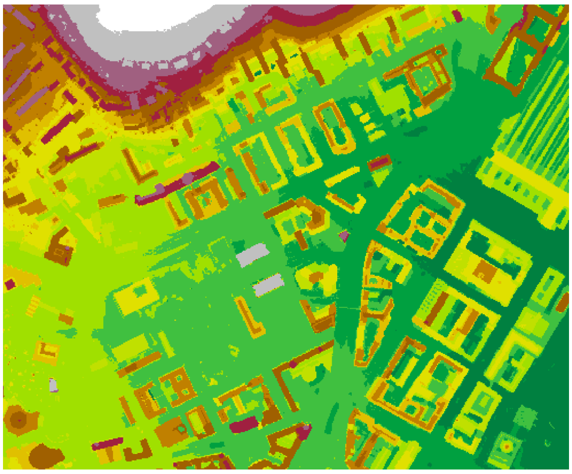

Figure 2: Original DSM, part of Stuttgart, interpolated to a 1 m^2 grid.

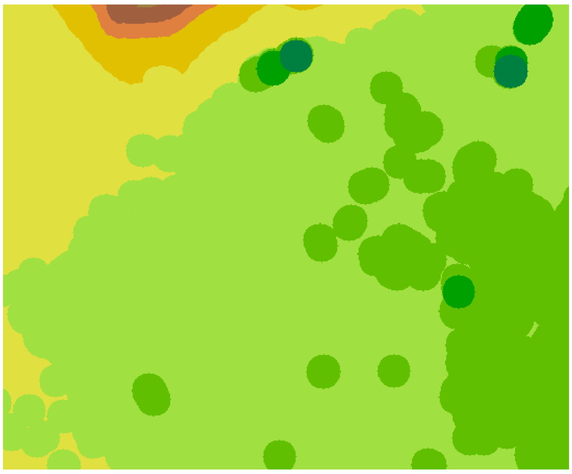

Figure 3: DSM after the erosion with a circular kernel.

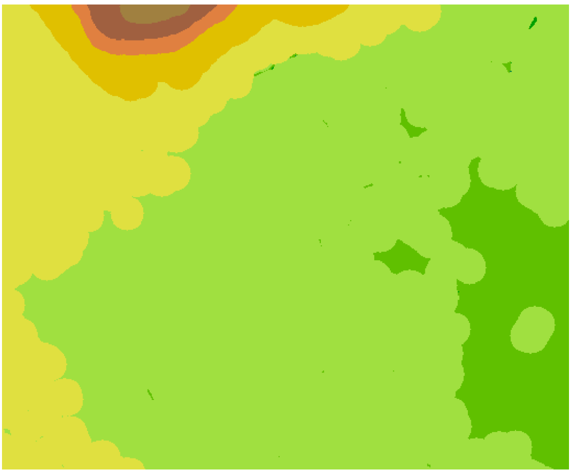

Figure 4: DSM after opening with a circular kernel.

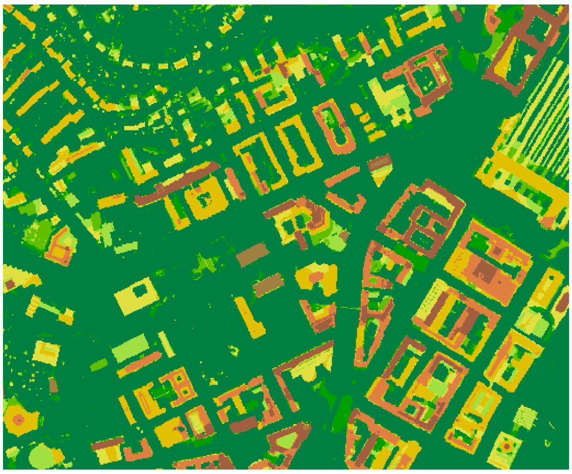

Figure 5: Final normalised DSM.

3.2 Volume Determination Using ATKIS Data as Prior Information

In our second approach we use street axes from ATKIS data to define the DTM (cf. Figure 1). Street heights usually represent the terrain level quite well.

In order to obtain height measurements, buffers are defined around the street axis segments given by ATKIS and all laser measurement points lying inside these buffers are selected (see Figure 6). Then, a triangulation of those points is performed to obtain a DTM. Figure 7 shows the final DTM.

As with the previous approach, the volume of blocks of buildings is determined by subtraction of the DTM from the DSM, however, in this case triangulated surfaces are subtracted instead of regular grids.

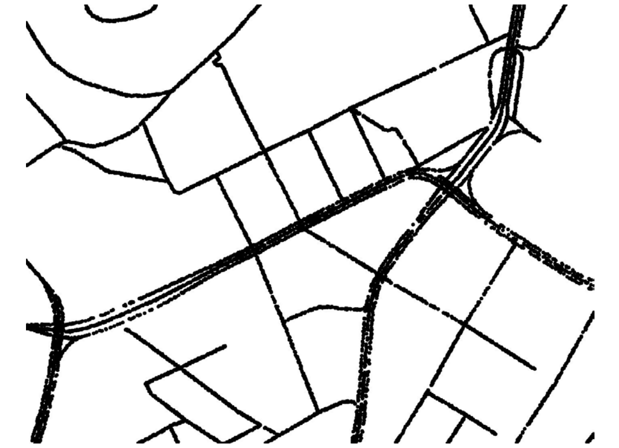

Figure 6: Points from the original (non-rastered) laser point cloud which lie close to street axes derived from ATKIS.

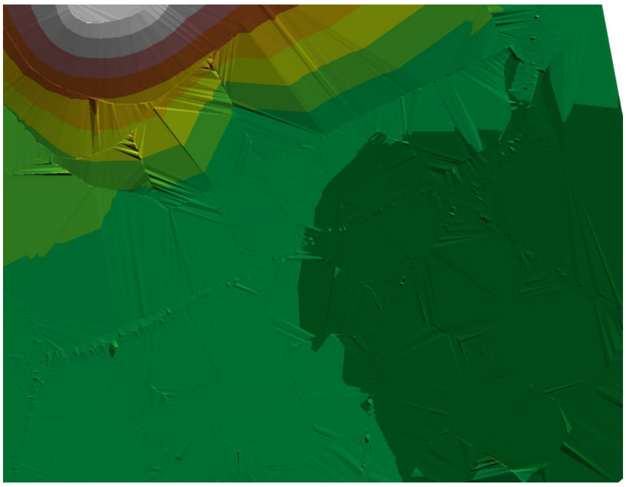

Figure 7: DTM derived from the points in Figure 6 by interpolation.

3.3 Volume Determination Using ALK Data as Prior Information

In this approach, we use ground plans of the buildings from ALK as prior information. All points inside the boundary are assumed to lie on the roof. Points outside the ground plans are considered to be ground points.

The idea is to calculate the arithmetic mean of all points within the boundary to obtain the average height of the roof. To obtain an estimate of the ground height, a buffer is defined around each ground plan and the terrain height is assumed to be the lowest point inside this buffer. Figure 8 shows the ground plans and the buffers.

The difference between the roof and the terrain is the height of the building. Figure 9 shows the 2.5D-buildings obtained by extruding the ground plans by the average height. The area can be easily obtained from the vector data of the ground plans. Multiplying height by area results in the building volume.

Figure 8: Original laser scan points, overlaid with ground plans and buffers for three blocks of buildings.

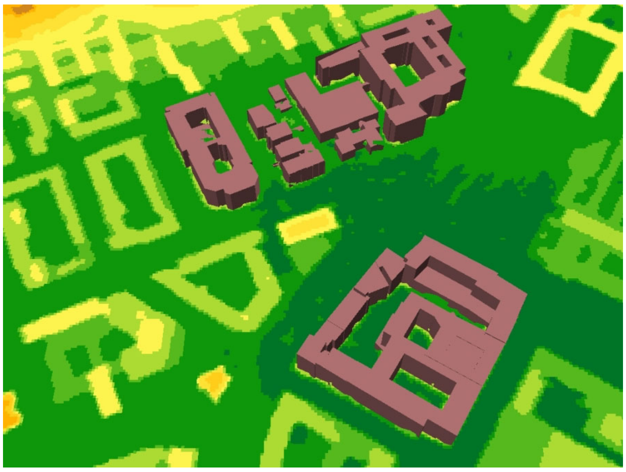

Figure 9: 2.5D view of resulting buildings.

3.4 Comparison with Building Volume Information

The volumes of three blocks of buildings are shown in table 1. The three columns correspond to the approaches presented in section 3.1, 3.2, and 3.3, respectively. One can see that the volume obtained by the third approach (ALK) is generally larger than the other two.

	Volume [m³]		
Block	Only Laser	ATKIS	ALK
1	77.796	78.695	81.088
2	222.688	226.082	241.829
3	239.376	233.770	252.066

Table 1: Volumes for three blocks of buildings, as obtained by the three presented approaches.

We compared those volumes to building volume information from the heat atlas of Stuttgart (Table 2). The volume consists of the aboveground and underground parts. The heat atlas also contains information about underground floors and aboveground floors. Assuming that all floors have the same height, the volume of the underground floors can be subtracted. From this, one obtains the third column of Table 2.

Block	Total volume [m³]	Volume without underground parts [m³]
1	165.303	93.500
2	191.412	145.000
3	317.631	257.000

Table 2: Volumes of building blocks, taken from the heat atlas of Stuttgart.

Comparing the calculated volumes of table 1 with the given volumes in table 2 shows that there are differences, especially for block number 2. One reason may be that the underground and aboveground floors have different heights. However, it seems more probable that in case of block 2, the heat atlas (dating back to 1993) is out of date and that new buildings have been built in the meantime.

Using the method just described, it is also possible to compare the volumes of single buildings. In addition to the three building blocks discussed above, we also tested an area with row houses and multifamily residences (Figure 10). The determined volumes fit quite well to the volumes of the heat atlas. The differences are only about one to five per cent.

Table 3 shows the determined volumes of some multi-story buildings from the town centre compared with the information from the heat atlas.

The values of some row houses are shown in table 4. These buildings have pitched roofs. The volumes of the attics are disregarded in the heat atlas because they are not heated. To compare the volumes the attic counts as another aboveground floor.

Information from the heat atlas					determined volume [m³]
volume [m³]	Floors above ground	Floors under ground	under ground parts [m³]	volume for comparing [m³]	
54650	6	4	-20936	33714	32120
25400	3	0	0	25400	25153
8913	3	1	-1486	7427	7880
47133	8	2	-9334	37799	38048

Table 3: Determined volumes of four multi-story buildings compared with the information from the heat atlas (town centre).

Information from the heat atlas					determined volume [m³]
volume [m³]	Floors above ground	Floors under ground	attic [m³]	volume for comparing [m³]	
(6 x) 945	3	0	+315	1260	1232-1322
(6 x) 1060	3	0	+360	1420	1459-1507

Table 4: Determined volumes of twelve row houses compared with the information from the heat atlas (suburb).

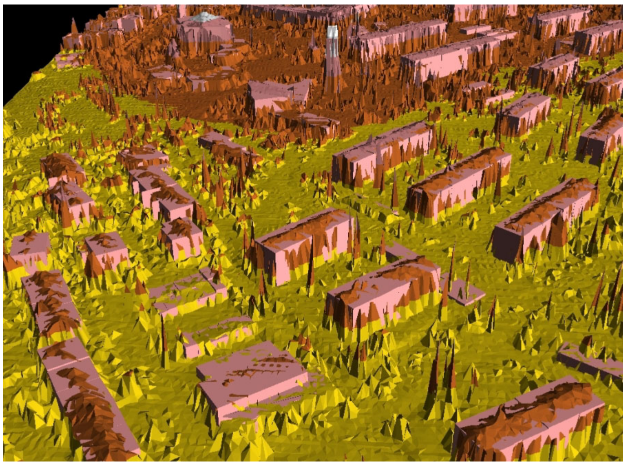

Figure 10: DSM and extruded buildings.

4. CONCLUSIONS AND OUTLOOK

In this paper, we described three different approaches to extract building volumes. The first one uses no prior information besides the original laser scan DSM, the second uses street axes from ATKIS data, whereas the third uses ground plans from ALK. Building volumes have been obtained for blocks of buildings in each case, and the potential of the third method to derive per-building volumes has been shown. We finally compared these volumes to information on converted space from the power authority's database.

In the future, we will refine the methods and investigate the differences between the derived volumes and the converted space according to the database. We also will enlarge the considered area in order to obtain a more reliable conclusion.

The method with ground plans as prior information provides the best results. If there is no prior information about the ground plans available, it makes sense to compute an approximation and proceed accordingly.

Finally, we will research how our results can be aggregated and combined with other datasets in order to derive an area covering heat atlas. Especially interesting is how our results interfere with more classical approaches which make use of building and settlement typologies.

ACKNOWLEDGEMENTS

We gratefully acknowledge the funding by the AGFW (Arbeitsgemeinschaft Fernwärme, e.V.). The laser scanning data was provided by the Landesvermessungsamt Baden-Württemberg, building ground plans by the Stadtmessungsamt Stuttgart.

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