# Improve 3D models from 2D images

T. Kostelijk
mailtjerk@gmail.com

September 2, 2011

## 1 Comments on this thesis

Dear Isaac,
This in an update of my thesis chapter. I incorporated most of the feedback except for
-the test on different datasets
(the dataset is not ready yet)
-references
-large introduction
I expanded the introduction a bit more then my previous version but I think you want more background information. I do this in a few chapters earlier which is not included in this document.
I processed a lot of small changes and the two big changes are:
I updated the way line segments are associated with building parts and illustrated it with Figure 10.
I wrote a new subsection about alternative roof-types.
Thanks in advance for reading my thesis chapter and giving me usefull feedback.

## 2 Improving the 3D building

### 2.1 Introduction

In the previous chapter we extracted the building contour with the skyline detector. The output was a set of 2D points and we collected this set for every view of the building. The aim of this chapter is to use this set of points to improve the basic 3D model.
The point cloud from the skyline detector included a lot of noise caused mostly by occluding objects like tree's. How do we detect those outliers? And if we have an outlier free point cloud how can we use this information to improve the 3D model? How can a point be associated to a specific part of the building and finally improve the 3D model? These questions are addressed in this chapter.
The solution is divided broadly in the following steps. First a basic 3D model is generated. *openstreetmap* gives us a photo of the building. The heights of the

walls are known because a top view of the building is used. From this top view image a basic 3D model with infinite height walls is generated.
Secondly the set of points returned by the skyline detector is transfered to a set of lines. Then each line segment is assigned to a wall of the building. After this the lines are projected to these assigned walls in the 3D model. These projections are used to estimate the new heights of the building walls. The 3D model is then improved by updating the walls according these heights.
We will now elaborate on the steps.

## 2.2 Extracting line segments

To remove the outliers the process is reversed: we detect the inliers and consider the remainder as outliers. But we first have to define an inlier.
Lets take the contour of an average building, this is mostly formed by straight lines. We use this fact to simplify our problem:
*Flat roof assumption*
*We assume that a building has a flat roof, implicating that each building-wall has a straight upper contour*
If a set of skyline pixels lie on the same line, they form a straight line and they have a large probability to present a part of the building contour. These skyline pixels, that form a straight line, are therefor considered as our inliers.
If we have a method that extracts straight line segments, we can use these line segments to find parts of the building contour and finally use this to improve the 3D model. ~~Next is explained how these straight line segments are extracted~~.

### 2.2.1 Hough transform

A widely used method for extracting line segments is the Hough transform (invented by P. Hough). We regard this as a suitable method because it is used a lot for this kind of problems. This is probably because it is unique in its low complexity (compared to other (iterative) methods like *RANSAC*). ~~We will explain this method briefly~~.
In the Hough transform, a main idea is to consider the characteristics of a straight line ~~not~~ as its image points $(x1, y1)$, $(x2, y2)$, etc., but in terms of the parameters of the straight line formula $y = mx + b$. i.e., the slope parameter $m$ and the intercept parameter $b$.
The input of a Hough transform is a binary image, in our case the output of the skyline detector (chapter TODO).
If a pixel is classified as a skyline pixel (a pixel that lies on the skyline according the skyline detector), the Hough transform increases a vote value for every valid line ($m$,$b$ pair) that crosses this particular pixel. Lines ($m$, $b$ pairs) that receive a large amount of votes contain a large amount of skyline pixels.
Because the algorithm detects straight lines containing only skyline pixels it is most likely that it returns parts of the skyline and therefor the building contour.
The Hough transform is implemented in *Matlab* and has some useful extra functions.

The main idea is

Therefore

The algorithm can optionally return the start- and endpoint of the found lines which is very useful as it helps to associate which part of the building is described by the line. Furthermore it has the parameter *FillGab* that specifies the distance between two line segments associated with the same $m$,$b$ pair. When the distance between the line segments is less then a specific value specified, it merges the line segments into a single line segment. In our application this parameter is of particular interest when we want to merge lines that are interrupted by for example an occluding tree.
Results of the Hough transform on the 2D output of the skyline detector are displayed and evaluated in the Result section.

too much specified

## 2.3 Associating line segments with building parts

### 2.3.1 Introduction

The Hough transform of the previous section returned a set of 2D line segments. If we could find a way to associate parts of the building with the 2D line segments, we can use this to improve our basic 3D model. This section explains how we associate the line segments with the best matching parts of the building.

Use the same time in a sentece could/ can is not good.

First the problem is analyzed and a few assumption are made. Then some heuristics are defined and finally the developed method is explained.

### 2.3.2 Assumptions

We treat the parts of the building as individual walls and associate each line segment with a wall of the building that is most likely responsible for that line segment.

Rephrase this: We consider each building as consisting on individual or separated walls.

*Unique wall assumption*:
*We assume that the output of the Hough transform are line segments that each represent the upper side of the contour of a single wall of the building*
If a line segment is assumed to represent a single wall then the projection to that wall should have a large line-wall overlap. To be more precise, lets define $l$ in $\mathbb{R}2$ as a line segment that is generated by the Hough transform. If we project $l$ to the plane spanned by a certain wall $W$, we get a line $l_{proj_W}$ in $\mathbb{R}3$. As we assumed, $l$ comes from the contour of wall $w$. It's easy to see that $l_{proj_W}$ should have a large overlap with $W$, and also should have a small overlap with the other walls.

I dont understand the need to define all these in R3 and so, I assume it is because you are going to define the overlap in mathematical terms a bit later, so for now I go on and ignore it.

*Largest line-wall overlap assumption*:
*A line segment is originated from the wall with the largest overlap with the projected line segment.*

~~Now we have defined the assumptions we explain the algorithm.~~

It is difficult to see what originated means. Try to be a more specific.

Be more specific. Having defined out assumptions we can now describe the line/wall matching algorithm.

### 2.3.3 Algorithm

The algorithm can be described broadly as follows:
A line segment is projected to all walls and the amount of line-wall overlap is calculated. The wall with the largest overlap with the specific line segment is classified as the most likely wall for that line segment. Next the line segments are projected to their most likely wall, the algorithm outputs this set of lines in $\mathbb{R}3$.
This line-wall overlap is calculated in different steps. First different types of overlap are explained. After the algorithm determines the *overlap type*, the overlap amount is determined and normalized.
$l_{proj_W}$ can overlap $W$ in four different scenarios, this is explained in Figure 10. The wall $W$ is spanned by $abcd$, and $l_{proj_W}$ is spanned by $vw$.

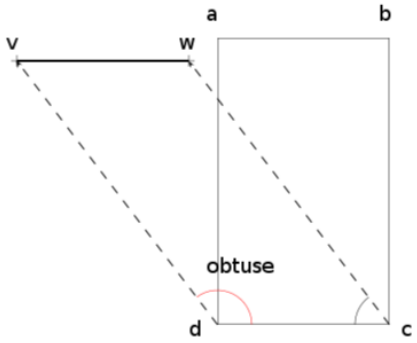
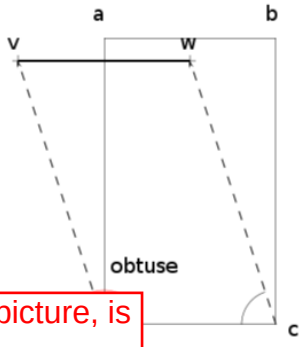


Figure 10a



I like this picture, is very clear.

Figure 10b

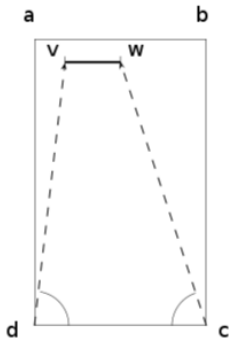


Figure 10c

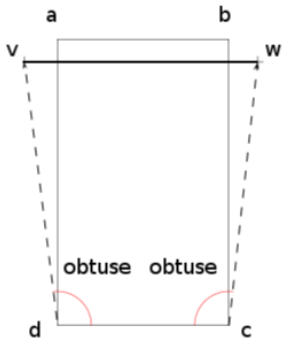


Figure 10d

The type of overlap is defined by exposing the endpoints of the line segments to an *in polygon* test where the polygon represents a wall of the building.
The table below represents the types of overlap with the corresponding number

of points that pass the *in polygon* test and their possible line-wall overlap value.

| Type of line-wall overlap | points in polygon | line-wall overlap |
|---|---|---|
| no overlap | 0 | 0 |
| partial overlap | 1 | [0..1] |
| full line-wall overlap (included) | 2 | 1 |
| full line-wall overlap (overextended) | 0 | 1 |

**No overlap** If the point in polygon test returns 0, the line-wall overlap calculation is skipped and 0 is returned. The remaining overlap types, partial and full, are treated individually:

**Partial overlap** Lets first consider the partial overlap type (Figure 10b), the *in polygon* test returned 1, that means that one of the line segments endpoint lies inside and one lies outside the wall.
To calculate the amount of line-wall overlap, the line segment is cropped to the part that overlaps the wall and the length is measured.
The cropped line has two coordinates, first of course the point that passed the *in polygon* test and secondly the intersection of the line segment with one of the vertical wall sides.
(Note that because we assume the walls to be of infinite height, the partial overlapping line segment always intersects one of the vertical wall sides.)
To determine which of the two vertical wall sides ($da$ or $cb$ from Figure 10b) is crossed, we determine on which side the point that didn't lie in the polygon (v) lies. This is done by an angle comparison (as in section TODO).
First, two groups of two vectors are defined: $dv$, $dc$ and $cw$, $cd$ (see Figure 10b). We measure the angles between the vectors and call them $\angle d$, and $\angle c$. Because one of the line segment endpoints lies outside the wall $\angle d$ or $\angle c$ is obtuse, in this case $\angle d$ is obtuse. (Note that this only holds under the assumption that all wall sides are orthogonal)
To be more precise:

- if $\angle d$ is obtuse, the left vertical wall side $da$, is crossed.
- If $\angle c$ is obtuse, the right vertical wall side $cb$, is crossed.

(The angles are acute or obtuse if the dot product of the vectors involved are respectively positive or negative. The advantage of this method is that it's simple and has low computational costs.) The amount of line-wall overlap is easy calculated by cutting of the point where $l$ intersects the determined vertical wall side ($da$ or $cb$) and measuring its remaining length.

No need for parenthesis here.

Put this assumption when you explain how the basic 3D model is constructed (above). You can say that you use gravity to create vertical walls spanning from the walls contained in openstreetmap.

This is actually the first place where you define the overlap measure. Try to define this a bit earlier or a bit

**Full or no overlap** Now lets consider the overlap types where the *in polygon* test returned 0. As you can see in Figure 10a and 10d this resulted in either full- or no overlap. Again we analyze the vector angles to determine the remaining overlap-type. If only one of the angles is obtuse, Figure 10a, with no points in the polygon then the whole line segment lies outside the wall. An overlap value of zero is returned.
Otherwise, if both angles $\angle d$ and $\angle c$ are obtuse or acute (Figure 10d), both endpoints lie on a different side of the wall, and cross the wall somewhere in between. Full overlap is concluded here.
The amount of overlap is now calculated by measuring the length of the line segment which is cut down by his intersections with *da* and *cb*. In this case this is the same as line *dc*, but its easy to see that this is not the case when the *vw* is skew.

This is important, so make it very clear.

Finally the line-wall overlap is norm nts length:
$\alpha_l = \frac{lwo}{|l|}$
Where $\alpha_l$ is the normalized line-wall overlap, *lwo* is the unnormalized amount of line-wall overlap, and ($|l|$) is the total length of the line segment.
The intuition behind this is that line segments that are likely to present a wall not only have a large overlap but also have a small part that has no overlap. By calculating the relative overlap, both amount of overlap and -missing overlap is taken into account.
The maximum of the normalized line-wall overlap is used to associate a line segment with its most likely wall. *should I place a formula here? and if yes how do I denote this mathematically legal/correct*
To summarize, the overlap type is defined by calculating the numbers of in polygon points and measuring some angles. Next the line segment is cut off depending on the overlap type and the line is normalized. A search for the maximum normalized line-wall overlap is used to determine the correct line-wall association.

### 2.3.4 Wall height estimation

In the previous section we associated the line segments with their most likely wall. In this section this information is used to estimate the height of the wall which is finally used to update the 3D model in the next section.
Now all line segments are associated with a certain wall we re-project the line segment from the different views on their associated wall. The re-projection is done by intersecting both endpoints of the line segment to the plane that is spanned by associated wall. Next the 3D intersection points are collected and averaged, this gives us an average of the midpoints of the projected line segments. We do this for every wall separately returning the average height of the line segments. These averages are then used as the new heights of the walls of the building.

### 2.3.5 Improving the 3D model

We made an assumption that a building consists of a flat roof (note that the walls may have different heights but the roof should be flat). In the previous section we calculated the new individual heights of the walls the building. This is propagated to the 3D model by adjusting the location of the existing upper corner points of the walls. We copy the bottom left and -right corner points and add the estimated height from the previous section to its y-value. FOOTNOTE:Note that this method assumes that the walls are aligned on the y-axis, which is in our dataset the case.

## 2.4 Results

Lets return to the output of the skyline detector in Figure 1. Figure 2


Figure 1:

shows the top 3 longest Houghlines, the endpoints are denoted with a black and blue cross. All three lines lie on the building contour. The left line covers only a part of the building wall. The middle line covers the full wall. The left and middle line are connected. The right line covers the wall until the tree occludes.

Figure 3 displays the line segments (originated from different views) projected

Figure 2:

onto their associated walls. For a clear view we only selected the lines that where associated with three specific walls of the building. The red cross in the middle of the line is representing the average of its endpoints.

Figure 4 displays the updated 3D model. The corner points of the walls are adjusted according the calculated wall heights. The green plane displays the augmented wall. The left and middle wall are extended and the right wall is shortened.

## 2.5 Discussion

We will now discuss the results. As can be seen in Figure **??** the left line segment doesn't cover the whole building wall. This is caused by using strict parameters in the Hough transform (like a small line thickness parameter). If some ascending skyline pixels fall just outside the Houghlines, a gap is created and the line segment is cut down at that point. This is however not a big problem because the lines are long enough to produce a good wall height estimate. Furthermore ~~their~~ there are at least 5 other lines (originated from different views) that support this estimate for this wall.

there are

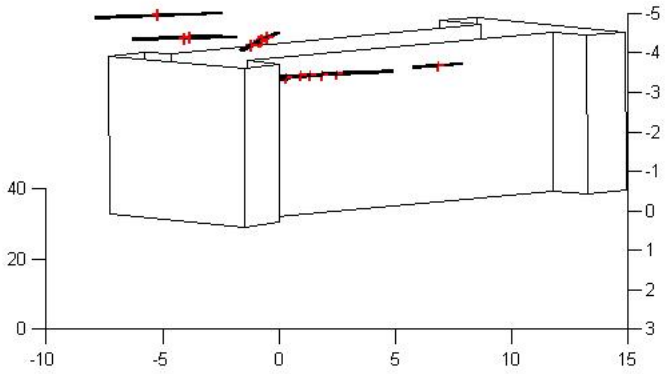



Figure 3:

### 2.5.1 Alternative roofs

Because of the flat roof assumption we didn't consider other roof types. We now discuss what adaptations the system should require to handle alternative roofs. In Figure 5, 6 different roof shapes are displayed.

Because we assume that the roof images are taken from the ground, the skyline detector will always detect the top of the building. In case of the flat roof assumption this was also the top of the building walls. In case of an alternative roof, this is just the top of the building and the building walls could lie a lot lower, something else needs to be developed to find the wall heights. It would be nice to develop a method that can detect which roof type we are dealing with, what the wall heights are, and finally generate an entire 3D model.
Some ideas about this are now proposed:
Use a object detector to detect doors, windows and dormers to estimate the number of floors, the location of the wall-roof separation and the exclusion of some roof types (e.g. a dormer is never located on a flat roof).
Use the Hough transform to search for horizontal lines between the ground plane and the high roof line to detect the wall-roof separation. Some buildings have a gutter, because of this fact the number of horizontal lines on the wall-roof separation will be larger which could be of good use.
Use geographic information (a database of roof types) with gps location to classify the roof type.

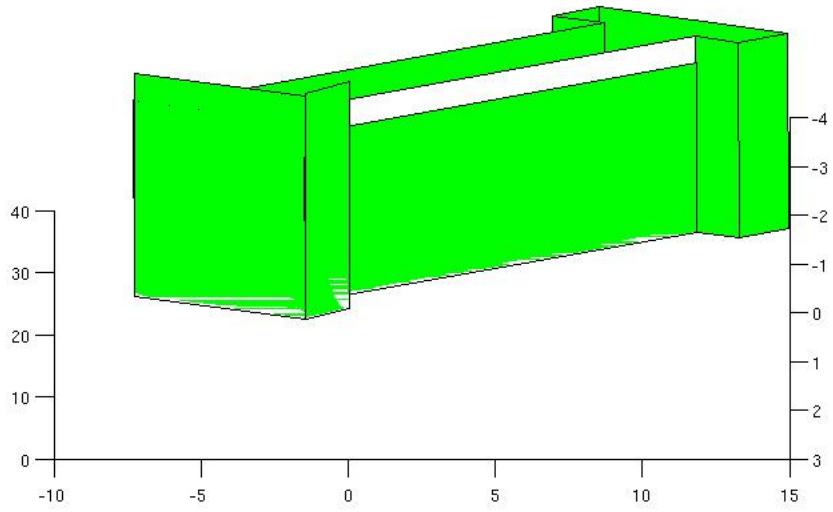



Figure 4:

The skyline detector detects the building height, if we could use predefined information about the ratio between the wall height and total height of the building, the wallheights could be estimated.
Assuming we determined the roof type, building height and wall heights, the 3D model could easy be generated.
For the *Gable* roof for example this will involve connecting the upper side of the walls with the high roof line (returned by the skyline detector). For the other roof types, the building height and wall height and a template structure of the roof could be used to generate the 3D model.

I think you conclusions are too much. You spend 3 out of 11 pages talking about what "would be nice". Try to make that a bit shorter, you want to put emphasis on your work, not on what would be nice.

## 2.6 Conclusion and Future work

We now discuss some future work and conclude. In this thesis little is discussed about the computational costs. This is because the computations are done efficiently (e.g. using matrix multiplications in Matlab) and off line, making the calculation process done in reasonable time. To make the application real time the next speedup would be useful.
To find the closest wall the middle point point of the line is now projected to all walls, it could be a significant speedup to reduce the set of walls to only

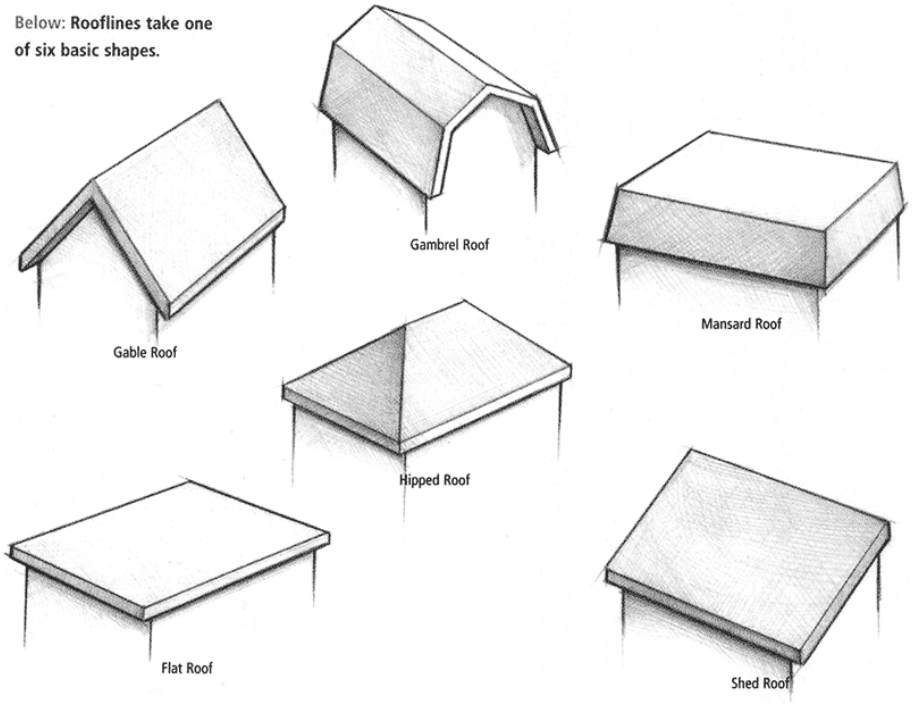



Figure 5:

the walls that are found at the endpoints. The downside is that it is slightly dangerous because it could be the case that both line segments endpoints could lie on a corner point making it possible that none of the endpoints refer to the correct wall.

As can be seen from Figure 3 two line segments appear on the same wall. This means they have a double influence on the average wall height which is unfair. A simple solution would be to add a normalization preprocess step so each view has only one wall height vote per wall. A more elegant solution would be to merge the two (or more) line segments to a single line segment. This could be achieved with an iterative Hough transform where the *FillGap* parameter is increased in each iteration. For fig ?? two iterations would be enough where the *FillGap* parameter needs to be at least as big as the occluding tree in the second iteration.
To make the algorithm more generic the flat roof assumption could be stretched or even discarded. Consider Figure TODO it has a roof consisting of two planes which are not parallel with the facade of the building. This makes the problem of extracting the 3D model more complex but not infeasible. By developing a method for this it would be smart to make symmetry assumptions. The roof lies exactly in the middle of the building and it consists of two symmetric planes,

this is useful information. In [REF] a polygon fit procedure is used where even dormers are recognized.

Furthermore it would be nice the fully discard the flat roof assumption. This will allow a building to have any shape, which is nice. The drawback is that a new method of outlier detection has to be developed. Object recognition could have a great deal in this. If one knows where for example an occluding object is located, then this could be used to filter the output of the skyline detector. This gives rise to a new problem that the 3D model has no augmentations at the position of occluding objects. Making sense of what would be behind the occluding object would be a interesting AI challenge and will incorporate pattern recognition, making use of repetitive structures and off course combining the multiple views to reveal as much information.

To conclude, we showed that a Houghline transform is a useful method to detect outliers and find prominent structure in the contour of a building with a flat roof. We introduced a method to pair up line segments with their associated walls. This was used to produce new wall heights which where propagated to the 3D model. Existing and novel AI computer vision techniques where powerful combined resulting in an accurate 3D model based on only a few calibrated 2D images.

## 2.7 References

TODO