# Graph-based Modeling of Building Roofs

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## ABSTRACT

Nowadays there are many applications based on 3D city models. While in the beginning, people were satisfied with about any boundary representation useful for visualization, it has meanwhile become apparent that data capture should focus on highly structured city models. Not only does this improve the usability for certain applications and the usefulness for later processing steps such as 3D generalization, but also, highly structured models are able to support automatic extraction processes by keeping the data interpretation within the bounds of a well-defined, structural model.

In this paper, we describe the use of region adjacency graphs for the structured modeling of building roofs. Our basic building blocks are simple building primitives, like flat or ridge shaped volumes, which can be combined to obtain more complex buildings. Additionally, different dormer shapes are defined as superstructures, which can be placed on top of the building primitives.

Using the region adjacency graph, modeling translates to the modification of the graph by matching and replacing (sub-) graphs.

## INTRODUCTION

Nowadays 3D-city modeling is a research theme which is used in many fields, for example for the analysis of wave propagation for planning antenna locations or car navigation to have more details to provide the user a more realistic surrounding area. These tasks are related to the problem of rebuilding city models true-to-life. Since the manual reconstruction is very time consuming and the costs are not affordable, the automation of this process is advisable.

In this paper we propose the modeling of buildings with the focus on the reconstruction of roofs. Such a roof structure is due to its complexity very multifarious, for this reason we firstly use aerial images in order to identify existing shapes. For each of the most often shapes we first construct a simple block model. To visualize the idea of the constraints we develop a corresponding graph. The constructed models are first independent from the real data and were compared in a later step with in LIDAR data detected roof shapes.

The paper is structured as follows. In the next section the background of the research is sketched and references to existing work are given. Then we present the idea of the block model and describe the basic shapes, which are the basis of our modeling. Subsequently we present the constraints we adopt at this stage and show examples e.g. of the extension of superstructures like dormers. The paper is concluded by a summary and outlook.

## RELATED WORK

Several researchers have dealt with the automatic reconstruction and modeling of buildings. Müller at al. (2006) proposed a procedural system for the modeling of buildings which are constructed using preliminary defined block models. Moreover façade elements can be tagged to this block model using a shape grammar. The modeling of buildings with additional details in the façade is possible this way.

A hierarchical modeling concept is introduced by Fischer et al. (1998). They use a “is-part-of” hierarchy to split up buildings and specialized the primitives using a “is-a” hierarchy to obtain a link between 2D and 3D primitive.

Some researchers provide the idea of a library for the building models. Taillandier (2005) determined roof shapes by combining planar faces and stored the resulting roof models in a library which can be used in the reconstruction process.
Lafarge et al. (2008a) used a predefined library of buildings with several roof shapes. Based on a single DEM and these basic shapes a reconstruction of larger areas can be done.
The idea to use a graph is provided by Verma et al. (2006). On the basis of a building detection from LIDAR data, a roof-topology graph and the related block models of buildings are constructed. The main information of the graph is the relationship between slopes of adjacent planar roof segments.
Besides this, Dörschlag et al. (2007) attached additional information to a graph. The characteristics "right-angled", "touching" and "parallel" are added to a graph as additional edges.

## BASIC IDEAS FOR RECONSTRUCTION

In this section we overview the models which we select as basic building shapes from aerial images. We represent these shapes as block models with geometric parameters which were used for modeling.

### Basic Shapes

The complexity of the roofs is an essential problem. To reconstruct the most of the buildings it is necessary to restrict the possibilities. As a tradeoff between a reliable shape detection and the ability to model a large percentage of the buildings, we choose five common basic shapes of buildings (as shown in Figure 1).

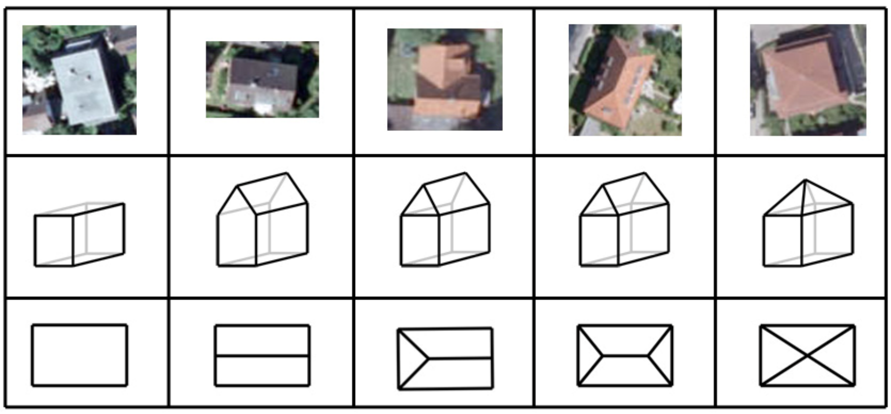
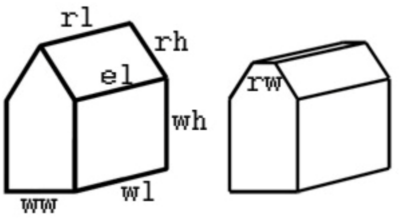


***Figure 1:*** The five basic shapes of the buildings. First row: Aerial images, second row: block model, third row: view from above.

To increase the possible level of complexity using these shapes, geometric parameters are added (see Figure 2) which all can be modified while modeling. The ridge width, for example, can be used to modify a gable roof into a mansard roof.




| | |
|---|---|
| WallWidth | ww |
| WallLength | wl |
| EavesLength | el |
| RidgeLength | rl |
| RoofHeigth | rh |
| EavesHeight | eh |
| RidgeWidth | rw |

***Figure 2:*** Additional parameters of the basic shapes of buildings.

The modeling of the buildings consequently starts with one of these basic shapes. During the following reconstruction, more basic shapes as well as extensions (like dormers) can be added.

## MODELING USING CONSTRAINTS

In this section we want to point out, what kinds of constraints are useful for the modeling of roofs. In (Milde et al. 2008) we described a method to detect simple roof shapes in aerial laser data. The detection itself depends on a region adjacency matrix which only uses a few characteristics of the roofs. From this we start to reconstruct the building roofs with an attributed grammar. But a problem is, that the most important information is inside the attributes and the number of the grammar rules is low. To develop the idea of the adjacent matrix and the further constraints of buildings and roofs we want to build up a graph containing additional information, which we can use for the modeling. Exemplarily we want to extend a gable roof with a dormer and show the extension with another basic shape.

### Extension of a dormer

The extension of a roof with a dormer provides certain constraints which we want to indicate by attaching a flat roof dormer to a gable roof.

The first constraint which must be fulfilled is that the dormer only can be attached to a roof side of a house. Since dormers are generally not attached to flat roofs, the additional restriction is that the roof face has to be sloped.

Furthermore the orientation of the dormer has to be constricted. This results in the constraint that the lower edge of the dormer has to be parallel to the lower edge of the roof face (Figure 3 - middle) and can for example not be attached in a twisted orientation. (Figure 3 - right).

Furthermore we divide these possibilities into two cases. The dormer can be completely inside the roof face that the edges are parallel or can be extended it the way that the edges are identical-parallel (Figure 3 – left). They are also merged in the graph.

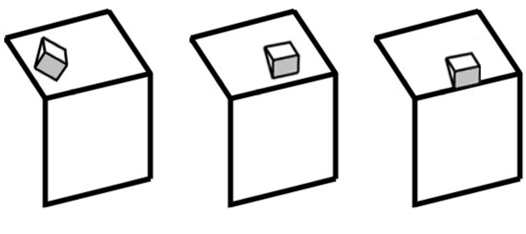


***Figure 3****:* Example which way a dormer can be attached and not.

Since the extension of a dormer are characterized by some restrictions to the roof face and the two roof edges, these three elements of the graph of a gable roof are needed to extend them with the graph of a dormer (see Figure 4). The roof face of the gable roof still exists in the graph and was only extended by a subgraph of the dormer. The geometric parameters determine if more shapes can be attached to this face.

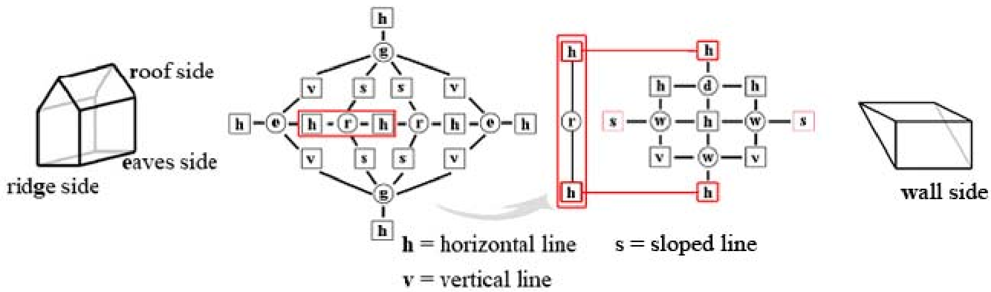



*Figure 4:* Graph of a gable roof and a terrace roof dormer and the combination.

## Example of an extension of a gable roof shape with another one

Just as we extend buildings with dormers, we also can enlarge them using other basic building shapes. The first extension criterion is the relative position of the two building shapes. Therefore it is not possible that the building only touches at a corner (see Figure 5).

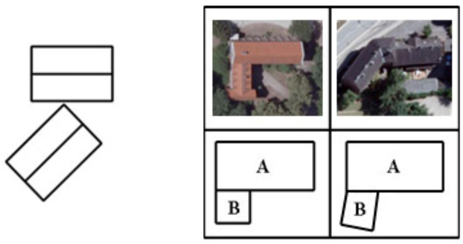



*Figure 5:* Left: Point contact of two gable roof shapes. Right: Orthogonal or sloped connection

To exclude this possibility we set the constraint that both buildings share at least two wall sides. If this constraint is fulfilled we distinguish between further cases. The first is if the extension is marginal or in the middle of the roof. Firstly we want to have a look at the marginal case. Here we distinguish between the two cases that either the two buildings sides form a common side or there is a partition edge between them so there are still two faces.

If two faces are merged to one common face there arise more possibilities of extension due to the larger wall. Within the graph both sides have been merged and the attributes have been interrelated to each other. Additionally, the edge can be removed. If the two buildings are out of alignment the leaves of the wall sides in the graph are not merged and the attributes are still separated. The possibilities of connecting building ground planes are described by Lafarge et al (2008b) for different cases. If the building B is extended in the middle of one side of building A then one side less than in the marginal case is involved.

## CONCLUSION

In this paper we presented constraints for modeling building roofs which are represented by a graph. We use aerial images to identify existing shapes and detect the most frequent shapes to construct block models and the corresponding region adjacency graph with additional information about types of the faces and the connections. We describe in which way the geometric attributes of the block model and the graph structure constrain the modeling of buildings or the extensions of dormers. In this way a majority of all buildings can be modeled and superstructures like dormers can be added. Using examples, we made clear that it is necessary to restrict the number of possible building extensions using suitable constraints. For further work we want to use these models to compare them with basic building shapes which we detect in LIDAR data sets in order to find the most appropriate reconstruction.

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