INTERPRETATION OF BUILDING PARTS FROM BOUNDARY REPRESENTATION

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ABSTRACT:

Different levels of detail for 3D city models can be generated automatically from highly detailed models using generalisation operations. To preserve the characteristics of buildings in this process, the semantic structures on the boundary have to be taken into account, namely windows, doors, chimneys, balconies, etc. In order to do so, these building parts have to be known, i.e. the geometric parts of a building have to be annotated semantically. In this paper, we start from an initial segmentation where a complex building model has been partitioned into parts based on a method from Computer Graphics. The goal is to assign the parts a meaning by using a rule based system. The rules are set up starting from a general building model, which already gives rise to geometric and topological properties; furthermore, common sense knowledge about buildings is introduced.

1. INTRODUCTION

The increasing availability of automatic methods to generate 3D city models as well as their usefulness for many applications (e.g. navigation, city planning, tourism) brings about also an increasing availability of such models. In order to handle the typically huge amounts of data abstraction and simplification mechanisms are needed that allow for a generation of different levels of detail (LoD). Such methods are investigated and developed in different research areas. In Computer Graphics, many approaches mainly work on polygonal or triangular meshes and reduce features based on geometric distance criteria. For an overview of these approaches see (Heckbert & Garland, 1997). Such methods are adequate for datasets that exhibit a high redundancy, e.g. data collected from laser scanners, where one plane can be represented by thousands of points. 3D building models, however, are typically of low redundancy, as they are described by their main constituting parts. A reduction method that only considers geometric criteria typically fails to preserve the important structures. Similarly, in 2D the well-known Douglas Peucker algorithm (Douglas & Peucker 1970) for line simplification is not adequate to preserve the typical structures of a building ground plan. Therefore, methods from another discipline, namely cartographic generalisation, are needed (e.g. Hake, Grünreich & Meng, 2002). There, procedures are available that take the specifics of the object and their importance into account.

In recent years, there has been a growing research in 3D-building generalisation. Kada (2002) uses and extends approaches from 2D building generalisation to 3D. Forberg & Mayer (2002) apply scale space approaches. Sester & Klein (1999) use 2D generalisation operations to simplify building façades and their elements, by e.g. aggregating adjacent windows or enlarging them. The prerequisite of that approach is that highly detailed building models, including semantically described buildings parts, are known.

Thiemann (2002) proposed an approach that tries to span the whole process starting from a boundary representation of the whole building as such, over the segmentation into meaningful parts, to the generalisation and hierarchical representation of the generalisation process. For the 2D-case, the decomposition of the generalisation sequence has been implemented in terms of so called simple features (Sester & Brenner, 2004).

The first step, namely the decomposition of the building into geometric parts has been realised using an adaptation of an algorithm by Ribelles et al. (2001) and is described in Thiemann & Sester (2004).
In this paper, the next step is presented, namely the interpretation of the geometric parts in terms of building elements like roof, wall or window.

Interpretation in general is a process that is needed for many applications in automation, e.g. interpretation of land-use classes, roads or buildings in digital images. Usually, a model for the objects to be found is applied. Depending on the degree of similarity between model and object different approaches can be taken, e.g. unary matching of attributes alone or relational matching (Vosselman et al., 2004). This is directly coupled with the necessary inference strategy that ranges from simple decision trees over production systems to search procedures. Depending on the degree of uncertainty of the facts involved, also uncertainty measures have to be taken into account (e.g. Shortliffe 1976).

In our case, a rule-based system based on a simple decision tree is used. For each building part, a set of characterising geometric and topologic attributes is defined. A special sequence of the interpretation allows for a certain degree of adaptation of the models.

The paper is structured as follows: in Section 2, the datasets and data formats used are described. Then, the segmentation method is briefly presented, as it is relevant for the types of parts that are generated and have to be interpreted. In Section 4, the building parts are described together with their characterising features. Finally, the interpretation strategy is given, represented as decision tree. Examples both with an artificial and real object show the potential of the approach. A summary and an outlook on future work conclude the paper.

2. INPUT DATA

The input data are building models in boundary representation without semantic information. In a bounding representation, a volume (e.g. a building) is modelled by its bounding faces. To describe a volume, only the geometry of the surfaces and their topology is needed. The topological elements are 3-cells (topological equivalent of a volume), 2-cells or meshes (surface), 1-cells or edges (lines/curves) and 0-cells or nodes (vertices/points) (see Figure 1).

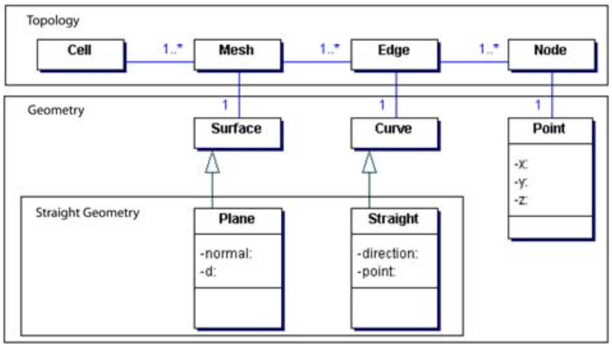

Figure 1. A simple model of a boundary representation for polyhedra with separated topology and geometry

The geometry can be described with the equations of the surfaces (e.g. the normal form for planes). The geometry of edges and nodes can be calculated from the geometry of the planes.

By restricting to planar geometry (polyhedra), an edge is a straight segment and can be calculated as the intersection of two planes. By intersecting two straight lines or three planes, the result is a point. By storing the geometry with the vertices as 3D coordinates, the model contains redundant information. This is more efficient but can cause inconsistency.

It is postulated that the dataset only contains real edges, which means the edges lie between two non-planar faces. In this case, features of the building, which are coplanar with the façade of the building, are not in the model.

3. SEGMENTATION

Features of the buildings are parts that stick out, form holes or can be added to fill a cut edge. These features can be separated from the building by an approach adopted from Ribelles et al. (2001). In case of a protrusion, the feature can be cut with an adjoining plane. In case of a gap, the open side(s) can be covered by one or more planes from the boundary.

Whether a plane is appropriate to split features can be determined with the following quotient:

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Area of the faces in the plane before
splitting divided by the area of new
inserted faces.
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There are cases, when either filling or cutting is possible, then filling is chosen (see Figure 2).

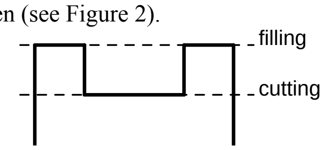

Figure 2. Filling or cutting? The quality quotient is 1.0 in both cases. Then filling is chosen.

There are some problems with sloped roofs and gaps (see Figure 3). Gap filling features can become very large and may intersect over building parts. A sloped roof can split neighbouring parts or buildings and their features diagonally, leading to unnatural building partitions.

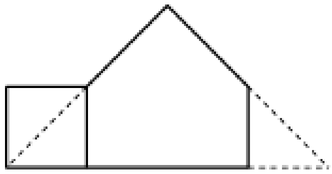

Figure 3. Problems with gaps - here at a pitched roof

The result of the segmentation is a set of geometric objects represented as volumes. There are some relations between the faces, the planes and the features. First, there are the topological relations from the boundary representation. A solid is bounded by faces, which are lying on planes. A feature is a solid that is separated by one or more planes from the rest of the building. It touches the building at one or more faces.

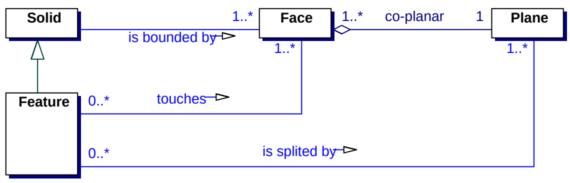

Figure 4. Relation between features solids, faces and planes

There are some constraints concerning the topology of features and faces (see Figure 5). A feature has to meet outside a face coplanar with the split plane (a-c) otherwise it is not a feature of this plane. In the result, the feature is always inside of one face coplanar with the split plane. If the feature is not completely inside the split plane (a), then the other faces meeting the feature will be affected too (d).

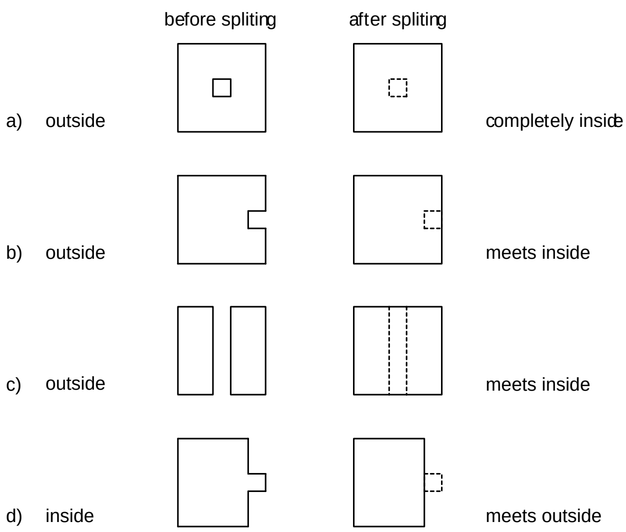

Figure 5. Topology of feature and the faces. A feature of a face always meets it before splitting. The name of the relation comes from the topological relation to the resulting face (after split).

4. INTERPRETATION APPROACH

Before we describe the interpretation process, we have a look at a general description of a building and its parts. Then we compare this model with the information we can get from our input dataset and set up our model for the interpretation.

4.1 Description of building parts

The **façade** is the front or outer cover of a building. Together with the roof and the base, it forms the closed space of a building. A wall is a vertical element. It divides always two spaces. Openings like doors and windows are necessary to let light, air or persons pass.

The **roof** is the top covering of a building. One can differentiate between slope roofs with typical inclinations over 25° and flat roofs with an inclination smaller than 10°. However, even a flat roof has always a small inclination.

A **window** is an opening in the wall of a building that allows letting light or air into the room and people to see out. Windows typically have a glass filling, which is held by a frame. If the window can be used to air, it has a frame and a sash. Otherwise, it is a fixed window. A **door** separates or connects two rooms or the inside with the outside of a building. Persons can go through. A **gate** is a big opening, where vehicles can pass.

A **balcony** is a platform projecting from the wall of the building and is enclosed with a balustrade. It is always localised in a higher level. A **bay** is a closed projection over one or more levels. A **loggia** is a room in an upper level with roofing, open to one or more sides. It does not project from the façade.

A **dormer** is a roof installation on a sloped roof. It is used to light and to air the roof level and to increase the useful area. It mostly includes a window. The front face is coplanar with or behind the façade of the building.

A **skylight** is a window in the roof. There can be also non-transparent openings, which are used to get on the roof.

The **roof projection** is the part of the roof that projects over the façade.

These descriptions above characterise the building parts; they contain many attributes that can potentially be used to classify these features and which are typically used by humans. These attributes are:

- Material and colour
- Size and form
- Relative position (in front of, behind, inside, touches, outside)
- Absolute position (height, distance)
- Direction (upwards, downwards, side-wards, horizontal, vertical, sloped)
- Connectivity
- Included parts
- Manoeuvrability (can be opened)

However, not all these information are included in the dataset, as we rely on geometric shapes alone. For example, material, colour and manoeuvrability can’t be calculated by analysing geometry and topology. The interior of the building is not included in the model, so only the outside - the façade - is interpretable. In addition, the frame of windows or the balustrade of a balcony is not expected in the dataset.
These descriptions do not contain sizes, because typical sizes of these features do not exist. There are too many exceptions from the rules. For example, a window can be as small as a toilet window and as big as the whole front of the room or even extend over more than one level.
Instead of using only absolute measures, it is better to use measures relative to the width of the façade, the height of the floor or façade, etc, too. The height of floors can be calculated by the vertical distance between two windows, this presumes, however, that windows already have been identified. Therefore, interpretation can be an iterative process.

4.2 Attributes for classification

Our implementation of the interpretation of the parts is based on rules represented in a decision tree. Before the algorithm checks the rules, appropriate attributes must be calculated for the segments derived in the previous step. The following attributes are best suited for the classification

- Inclination of the split plane: zeta
- Behind or in front of the façade / roof: behind, in_front
- Height over ground: h
- Parallel to the split plane or vertical: parallel, vertical

Nevertheless, these attributes are not enough to get an interpretation. So following attributes will be calculated too:

- The area of a face or of all faces in a plane: area
- The number of faces in the plane: number_faces
- The minimum enclosing rectangle of the face or of all faces in the plane: mer

The following attributes will be calculated for solid features. The bounding boxes in the global coordinate system (dx,dy,dz) and in a split plane based coordinate system (v,w,d – see Figure 6). d is the length along the plane normal; w is the horizontal distance and v the distance rectangular to w coplanar with the plane. To calculate these values, the body is transformed into the plane coordinate system.

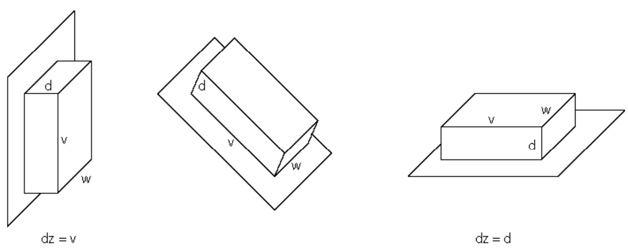

Figure 6. Split plane based coordinate system (v,w,d)

In addition, the feature volume and the volumes of the bounding boxes are calculated. The quotient of the volume of bounding box and real volume is a measure for the approximation quality of the bounding box. The measures of the better approximating box will be ordered increasingly. This leads to the parameters a, b and c where $a \geq b \geq c$.
By grouping features with the same extents lying in the same face or plane and with the same position in front or behind the face, for example, it is possible to identify the number of windows in a wall.

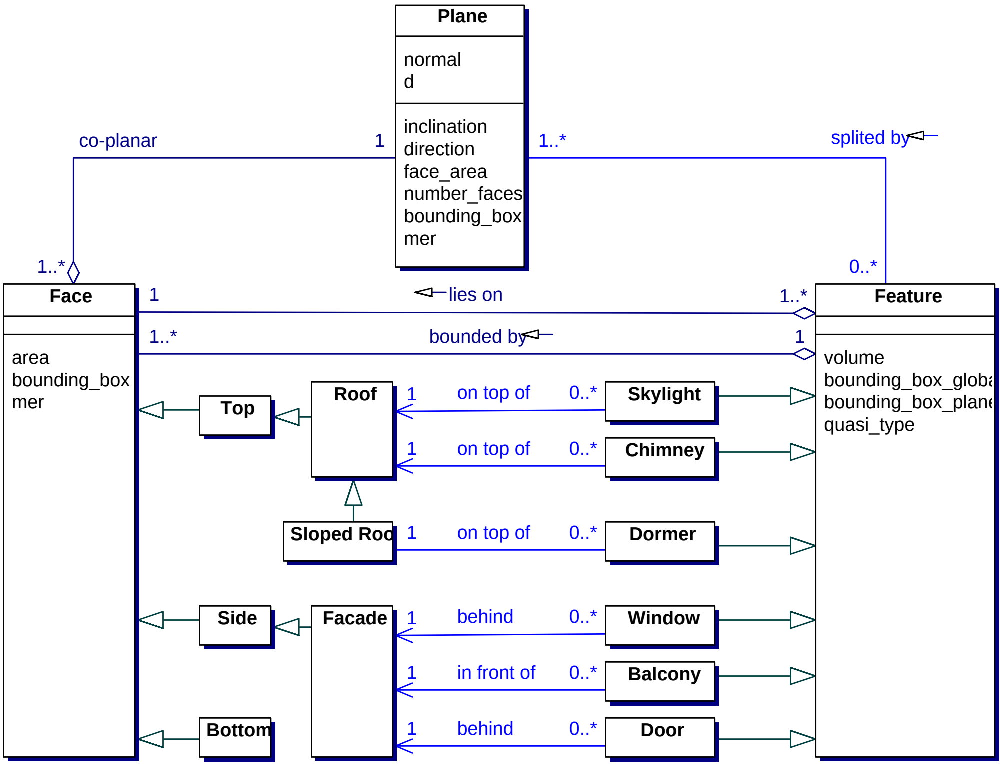

Figure 7. Simple model of a building

4.3 Our building model

The interpretation starts with classifying the bounding faces. Then the solid features are analysed. A classification of edges and vertices would also be possible, but this is not subject of this paper. In the following, our building model is described (see Figure 7).

A building is bounded by its façades (or wall-faces), the roof-faces and the base-face. Features of the base are not of our interest. Façades and roofs contain features, which are lying behind or in front of these surfaces. The planes and indirectly the faces can be classified by their slope. A distinction into the following orientations is made: side, top and bottom. A side plane has an inclination of about 90°. Top faces have inclinations smaller than 90°, bottom faces higher than 90°. The base is a special kind of bottom face. Features within the base will be ignored.

A **façade** is a side plane. Features lying in front of a façade are, for example, balconies, bays, extensions or windowsills. Windows, doors, gates or loggias are features that normally lie behind the façades.
A **roof** is a top face. Flat roofs have an inclination smaller than 10°. Roof features are typically lying on top of the roof, so the rain does not ingress. Some examples are chimneys, skylights, solar collectors, dormers and openings.

Some features touch more than one face. A simple example is a chimney standing on the ridge of the roof. Chamfers on edges or vertices are even more complicated. Such a gap can e.g. be found on a hipped roof. Another type of feature is the roof projection. It lies in front of the façade and is a part of the roof.

The solid features are bounded by faces, which also can contain solid features. For example, bays and dormers typically contain windows.
Based on this model the following descriptions for the building parts can be defined. Table 1 lists the topological and geometrical rules. Not all of them are yet part of the first implementation. As visible, some general size limits for the objects have been defined empirically.

Solid features	Face	Face relation	Height relation	Size limits [m]	Features
dormer	roof	in front		$dz > 0.5$ $b > 1$	windows doors
skylight	roof	parallel in front		$d < 0.2$	none
chimney	roof	in front			none
window	façade	parallel behind	over ground	$d < 0.5$ $dz < dz_{floor}$	none
door	façade	parallel behind	on / over ground	$d < 0.5$ $2 \leq h < dz_{floor}$	none
set-off	façade	behind			any
balcony	façade	in front	over ground	$b > 1, d < 2$ $1 < dz < 1.5$	none
loggia	façade	behind	over ground	$d > 1, b > 1$ $2 < dz < dz_{floor}$	none
bay	façade	in front	over ground	$d > 0.5, b > 2$ $dz \geq dz_{floor}$	windows
protrusion	façade	in front	on ground	$dz \geq dz_{floor}$	any
extension	façade	in front	on ground	$dz > 2$ $w > 1, b > 1$	any
roof projection	façade	in front	over façade	$w \geq w_{façade}$	none

Table 1. Topological and geometric rules for object characterisation

4.4 First Implementation

A first implementation was done in a diploma thesis (Bolte 2005). The simple rules from Table 1 where transformed into a decision tree. The interpretation strategy is as follows: first, the planes of the original model are classified. The first criterion is the inclination of the faces; the second is the area of the coplanar faces. A value for the minimum area of facades is used to let small faces, like the faces of windows, the chimney etc. unclassified. The algorithm was tested on two buildings: an artificial standard house and a real building on the campus of the university of Hanover. In the first implementation the height over ground level was not checked, so the bottom of the roof projection in the first example is classified as bottom face too (see Figure 8).

The solid features are classified in the second step. In our first implementation, only small features are interpreted. Therefore all features with a volume bigger than 100 m³ are ignored. If the feature was separated with more than one, it is classified as gap. Depending on the interpretation of the split plane, it can be differentiated between façade and roof features. If the split plane is a roof, only features on top of it will be interpreted. To differentiate between skylights, chimneys and dormers some empirical values are used. At a façade, features may be located behind or in front of the wall. Behind the façade it will be distinguished between loggia, door, window and set-off dependent on their size. In front of the façade bays, protrusions, roof projections and balconies are differentiated with width and height.

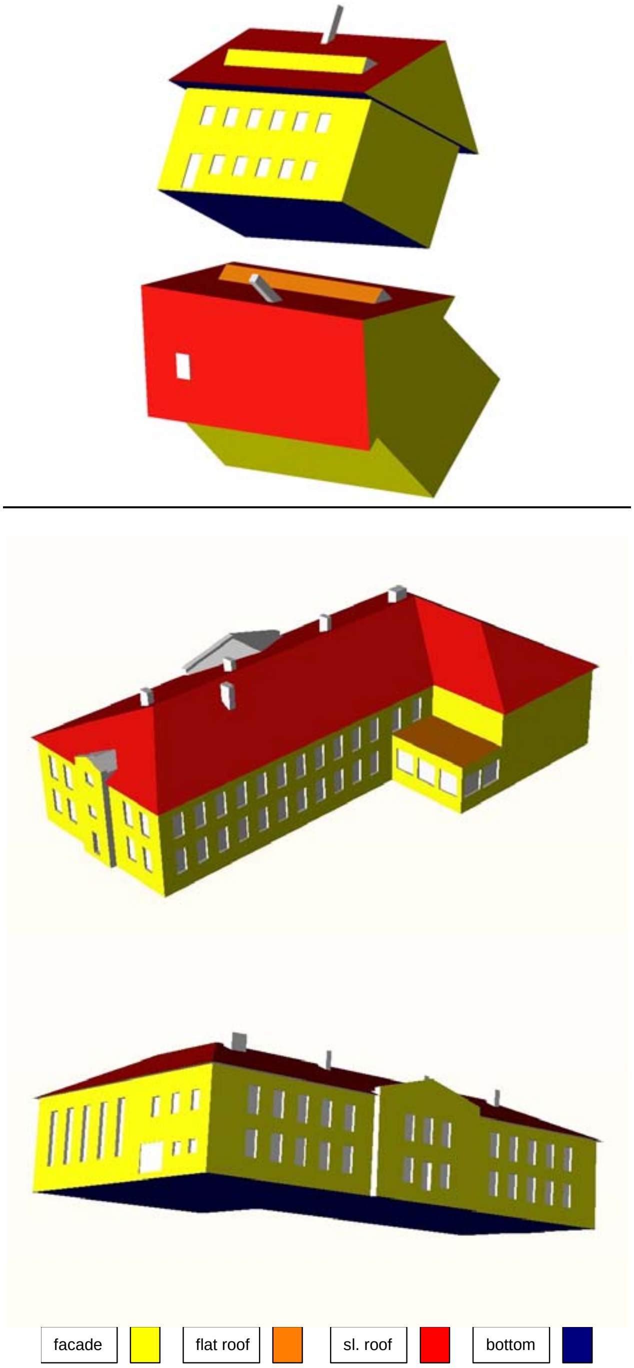

Figure 8: Result of the interpretation of the faces

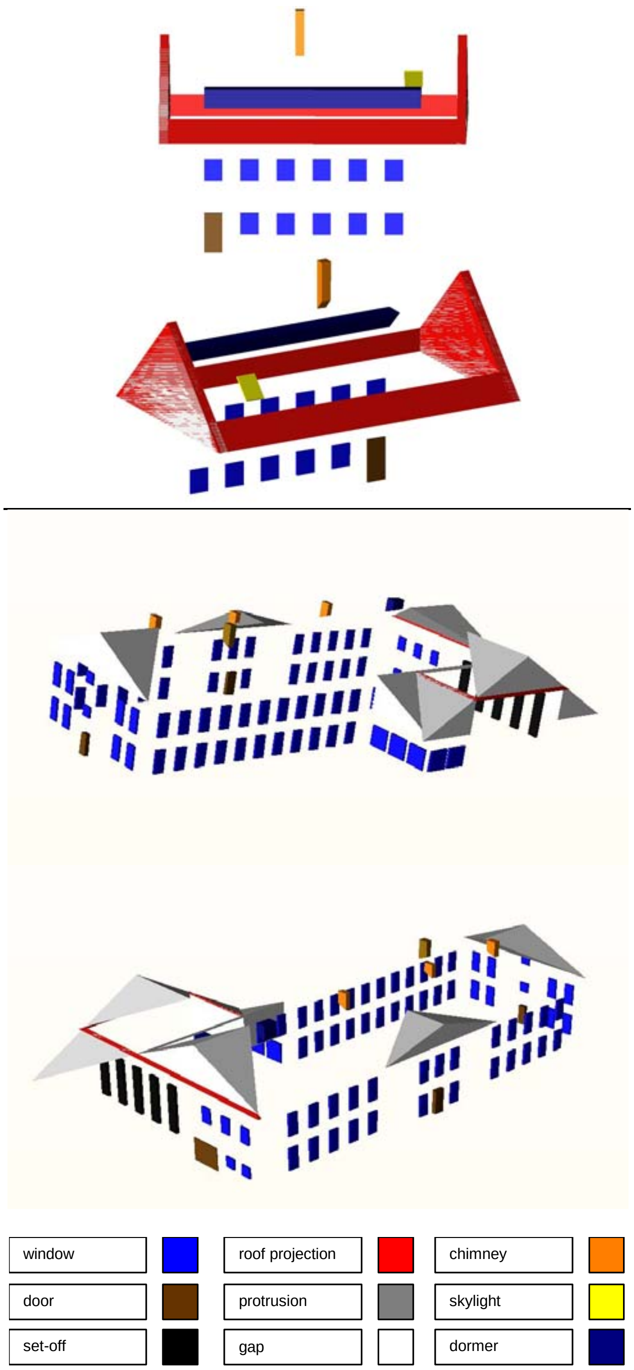

Figure 9. Result of the interpretation of the solid features

Most features of the example buildings are interpreted correctly. Some problems occur at windows, doors and set-offs. It is not possible to differentiate them only with their size. The windows in the second example are higher than two meters. To distinguish them from doors, the height above the floor has to be analysed, but this is not included in the program yet. Currently, we use a very simple criterion, namely we do not allow more than two doors of the same size in a building. The big windows on the left of the second example (see arrow) were interpreted as set-offs. This is because they are higher than the normal distance between two floors. Without colour or material attributes, it is not possible to differentiate them reliable if the set-offs have the same distance d from split-plane as windows. The grey features are the filled gaps of the hipped roof and some artefacts of the segmentation, which can be avoided by using limit values for volume or size.

5. DISCUSSION AND OUTLOOK

In the paper, we presented a rule-based approach for the interpretation of building parts from a segmentation of a whole building object. The definitions of the individual parts were specified using geometric and topologic attributes and constraints. The results are promising. Even for a complex real world building, the majority of parts have been identified correctly.

However, there is also room for improvement. The thresholds for the characteristics of the object parts have been determined and fixed based on empirical investigations. In cases where deviations from typical object characteristics occur, recognition is not possible. In order to compensate for that, more adaptivity will be introduced in the reasoning process. This will be done in a more modular set up of the inference procedure that allows for the identification of higher level objects, which, in turn, can give rise to certain parameter settings within their context. E.g., the detection of a large uninterpreted object in a wall may be re-interpreted as a window by adapting the thresholds. Other refinements might be necessary, by including more spatial context, e.g. a window has to have similar size like its windows neighbouring.

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