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Handling Irregularities of 3D Building Data During Surface Computation

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Abstract

Real-world data, esp. three-dimensional measurements of buildings, contain various irregularities, e.g. common vertices of building parts. These irregularities cause large problems in data conversion from CSG to B-rep. We will present an approach which can tackle these irregularities using geometrical properties of buildings and extensions of basic operations from the field of analytic geometry. An extensive 3D scene will be described and converted.

1 Introduction

A broad application of real-world 3D building data has been observed for environmental and city planning, transmitter placement, architectural construction and animation, to mention a few out of many examples. These data can be acquired efficiently using (aerial) images of urban scenes and a *computer-aided reconstruction system (CAR)* for buildings as described in e.g. (Braun et al. 1995; Englert and Gülch 1996). A common data structure for building modeling is *Constructive Solid Geometry (CSG)*. Hence, for further processing, e.g. surface analysis, these data need to be converted to *Boundary Representation (B-rep)*.

Real-world measurements lack in numerical accuracy and in data completeness. In order to tackle these irregularities we are focusing our approach on geometrical properties of buildings (Section 2.1) and additionally, we have extended the computation of basic operations from the field of analytic geometry which are used for the conversion (Section 2.2). These extensions lead to a robust algorithm which computes a *minimal B-rep*, whereas 'minimal' refers to the number of faces and vertices (Section 2.3). Finally, in Section 3 we will describe a three-dimensional building data set of a village close to Bonn consisting of 1770 groups of buildings, and furthermore its conversion to B-rep. We conclude with a description of future work.

2 Conversion of CSG Building Data to B-rep

In this section difficulties arising during the conversion of CSG building data to B-rep are discussed and solved by using geometrical properties of buildings and extensions of basic operations from the field of analytic geometry. The algorithms are depicted briefly. For a more detailed version we refer the interested reader to the description of the system COBREP (Englert 1996).

2.1 Geometrical Properties of Buildings

For reasons of efficient acquisition 3D building data are based on CSG or more precisely, binary trees where leaves contain solids[1] and pose- and form parameters (affine transformation and scaling) and interior nodes (including the root) contain Boolean operations. Solids are internally represented as polyhedra by vertices v,

[1] Box, chock, cone, cylinder, ...

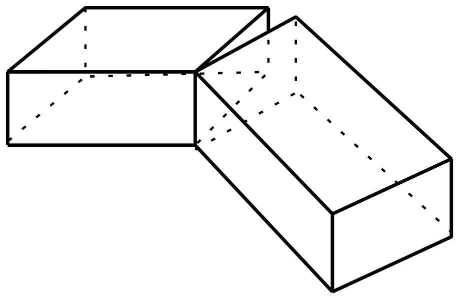

Figure 1: A building consisting of two flat roof building parts. They are touching at an edge. It has been modeled using two boxes with a 'common' edge.

edges[2] e, and faces f assuming that the vertices of a face are right-oriented. The latter assumption ensures that the B-rep is unique and hence it can be realized in the three-dimensional Euclidean Space E^3.

To model buildings representation problems arise: buildings are not 2-manifolds[3]. The problem is that the surface intersects itself at a segment (cf. Figure 1). For practical purpose, such buildings can be represented as a 2-manifold by 'ignoring' the exceptional segment. One possibility to do this is to represent the building of Figure 1 as a rigid combination of two buildings which touch each other at a common segment. In this case the Euler equation[4] $|v| - |e| + |f| = 2$ does not hold anymore. However the Euler characteristic $\chi(S) = |v| - |e| + |f|$, where S is the surface of a solid, remains constant. Hence, alternations of a B-rep are permissible, especially the minimization of the number of faces and vertices.

Buildings are tectonic constructions in origin and thus geometrical properties hold. In suburban areas one can easily verify the following general properties (Englert 1996) taken from aerial images (cf. Figure 2):

1. The ground level of a building is in general plane. Hence it is constant for the base polygon of a building.

[2]Interchangeable edges are called segments.

[3]A 2-manifold M is a topological space where every point has a neighborhood topologically equivalent to an open disk of E^2 (Mäntylä 1988).

[4]$|\cdot|$ denotes the cardinality of a set.

Figure 2: An aerial image of a village close to Bonn showing different geometrical properties of buildings, resp. roofs.

2. Most walls touch incident walls right-angled.
3. Nearly all roof faces (or neighboring faces of them) reach up to the roof height and meet at the ridge (in point or at edge). Buildings have in most cases a gutter with constant height.
4. Generalized building descriptions (Englert and Gülch 1996) have no wholes or indentations.

These properties reduce the computational complexity and the classification ambiguities of intersecting points; they are used intensively in Section 2.3, e.g. item 3 makes it possible to compute separately the surface of a roof.

2.2 Irregularities Influencing Analytic Geometry

The system has to tackle a variety of data irregularities due to

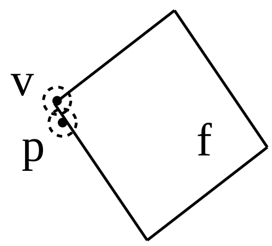

Figure 3: Assume, face f is defined in a manner that point p "touches" f (indicated by the dashed circle) and v is a vertex of f. Due to the inaccuracy of the polygon defining f p could be classified as *not coincident* to v, even it is (indicated by the intersection of dashed circles).

measurement: vertex positions depend strongly on the accuracy of the given image orientations and the cameras used to take the photographs from which the images for data acquisition are generated and on the measuring operator;

storing: building descriptions require a compact format and thus the origin data accuracy will often be decreased during storing;

computation: the multiplication and the division of real numbers cause not ignorable rounding errors (Wilkinson 1963). Furthermore defining a face by three vertices it can happen that the remaining vertices of the face have a distance bigger than a small value ϵ to the face. Li, Sun, and Tang (1990) propose a method to improve the reliability of Boolean operations based on point classification (Mäntylä 1988). Nevertheless, if a point p "touches" a face f close to a vertex v of f, then it might take place that v will be classified as not coincident to p, even it is (cf. Figure 3).

incompleteness: incomplete data include that e.g. faces may emanate from "closed physical objects". Hence such buildings are not 2-manifolds again.

As consequence an integrity check of the modeled buildings as proposed in e.g. (Mäntylä 1988) is not possible. Instead, the geometrical properties described in the previous section can be checked.

2.3 Union of Building Polyhedra

The approach can be separated into two parts: first, the computation and classification of intersecting points and second, a post processing which is a minimization of the resulting B-rep. The main algorithm takes as input a CSG tree C, unites its solids, minimizes the resulting B-rep B, and stores B as VRML[5] world:

1. For all solids s from C do
   (a) For all faces f from s do
      i. For all faces f_b from B do
         A. Intersect f with f_b and insert intersecting points into both faces
         B. Classify vertices of face f as "before", "on", or "behind" according to f_b and to their orientations, and vice versa
      ii. Reclassify and remove coincident vertices of B
      iii. Add f to B
2. Minimize B

The intersection of faces and the point classification (paragraphs 1(a)iA and 1(a)iB) make intensively use of the properties described above. Hence we will consider them in more detail. The former takes as input a face f and the currently computed B-rep B and modifies both as following:

1. For all faces f_b of B do
   (a) For all segments s of f intersect s with f_b and protocol the intersecting point p in I.
   An intersection exists if the embedding line of s intersects the embedding plane of f with a parameter t, where $0 \leq t \leq 1$, and p lays in f. The latter condition can be checked using Jordan's half-line theorem (Laurini

[5] Virtual Reality Modeling Language, e.g. `http://www.dur.ac.uk/~dcs3py/pages/work/Documents/`

and Thompson 1994) taking into account that p lays not on a vertex or segment of f and the constructed half-line is not collinear to any segment of f. The coincidence of points is tested by computing the intersection of two spheres with prefixed radius. Finally, the intersection of two segments can be computed by minimizing the squared Euclidean distance $||l_1 - l_2||^2$ of their embedding lines l_1 and l_2 and checking whether the distance of the intersecting point to both segments is less than a small prefixed value ϵ.

(b) Classify points p of I whether they lie on a segment s of f_b and determine a right-handed orientation of I. Determine a start point a of I using the classification.
The classification uses Hesse's formula in order to compute the distance d of p and the embedding line of s. If d is close to zero, then it will be checked if p lies between the start- and end point of s.

(c) Insert I into faces f and f_b according to the intersected segments, resp. point a.

The point classification determines the relative position of a point to a face. Again, points are treated as spheres with prefixed radius. They are classified in the following sequence being "behind", "on", or "before" a face f according to the orientation of f. Note, all intersecting points will be classified as "on".

The post processing (paragraph 2) minimizes the B-rep. It consists of the following steps: merging coplanar and touching faces, classification and elimination of inner faces or parts of faces, and removing of redundant vertices.

Interior faces or inner parts of faces are determined using an extension of Jordan's half-line theorem (Englert 1996). Their elimination may result in redundant vertices, in other words vertices which are not used in the B-rep anymore. These redundant vertices are removed. Finally, the resulting B-rep will be stored as VRML world including a scene description for illumination, etc.

3 3D Building Data of a Village and their Conversion

In this section we will demonstrate the operability and robustness of our approach. As a test field we have chosen a village close to Bonn from which 1770 groups of buildings (short: buildings) have been modeled three-dimensionally with a low degree of generalization (Englert and Gülch 1996) which includes e.g. detailed roof structures, eaves, canopies: 745 buildings have a complex roof structure (no flat- or lean-to roof) and hence are of major interest (cf. Figure 2). The buildings can be grouped together into three classes: (a) detached houses (489), (b) any combination of two basic building types[6] (162), e.g. a L-shaped hip- and saddleback roof building, and (c) buildings which consist of more than two basic building types (94). Note, in most cases a combination of basic building types mean that some of the buildings are nested or closely interlocking and thus result in a complex roof structure and in an irregular ground plane.

Each group of buildings has been modeled by one CSG tree. All CSG trees were stored separately. The conversion of the 3D building data to B-rep has been performed fully automatically using the system COBREP. Since B-reps of objects can easily be visualized the converted data have been examined by an operator using a viewer[7]. Figure 4 demonstrates a group of buildings consisting of a variety of saddleback roof buildings: two symmetric -, two lop-sided - (one with a flat roof tower), and two closely interlocking saddleback roof buildings. All basic building types of a building were measured independently one after the other. Hence the acquired data contain the above described irregularities. Furthermore, the complexity of the roof structure demonstrates the robustness of the algorithm.

[6] Flat-, pent-, saddleback-, hip-, broach-, hipped-gable -, and mansard roof building.

[7] WEBSPACE^{TM} Navigator 1.1

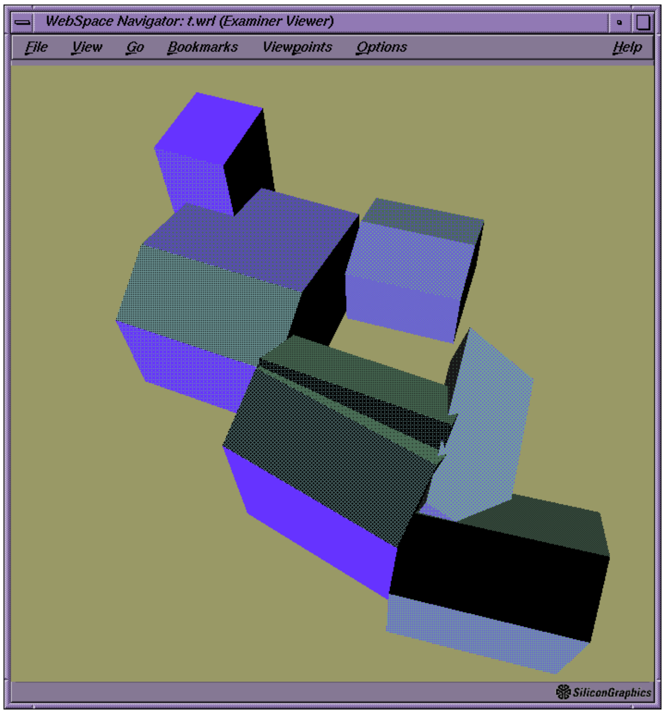

Figure 4: Different combinations and variations of saddleback roof buildings.

4 Conclusion and Future Work

We have presented a robust approach for 3D building data conversion from CSG representation to B-rep. The approach presented can tackle a variety of data irregularities, e.g. numerical inaccuracies. Those B-rep data are usable for a diversity of tasks. Currently we are exploring common structures of buildings, esp. roofs, by learning geometrical regularities in order to enhance automatic building reconstruction and urban scene modeling.

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