Semi-automatic Roof Reconstruction

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Abstract

A semi-automatic 3D roof reconstruction method is proposed in this paper. It consists of two components: automatic recognition of 2D plane drawings and interactively "pulling" or "pushing" the recognized results. Only a limited number of reconstruction operations are needed to generate various types of 3D roofs, making the method efficient.

Key words: *roof reconstruction, pulling, pushing*

1. Introduction

3D reconstruction from 2D orthographic views has been widely discussed in engineering industries in the last decades [1-5]. However, there has been little progress in the development of 3D roof reconstruction [6-7]. Current algorithms like purely geometric methods, fleshing-out projection algorithms, and volume-oriented algorithms have limitations to generate 3D roofs due to the following reasons. First, these methods only apply to the geometric part of the drawing, but roof reconstruction is strongly context dependent and needs mix the geometry with architectural semantics. Second, roofs are more artistic than other types of engineering entities, making the reconstruction process complicated.

Motivated by our previous work of rapid quantity surveying and construction directly from 2D drawings [8], we propose a new semi-automatic reconstruction method to efficiently generate 3D roofs in this paper. It consists of two components: recognition of architectural entities from a 2D plane roof drawing, and interactive reconstruction of various types of 3D roofs. We first recognize the contours of columns, walls or beams from the given plane roof drawing. It is built upon our previous work in automatic recognition of dimensions, coordinate systems and structural entities [9]. Then we reconstruct 3D roofs by simply "pulling" or "pushing" the recognized results. Various types of 3D roofs used in real-life applications can be quickly generated by a limited number of reconstruction operations.

The rest of the paper is organized as follows. Section 2 discusses the characteristics of typical types of 3D roofs. Section 3 introduces the proposed semi-automatic 3D roof reconstruction method. Finally Section 4 provides a summary of this work.

2. Characteristics of roofs

Roofs are one type of the most artistic architectural entities. Fig. 1 shows some examples with varied shapes and usages. Fig. 1(a) is a simple flat roof, while Fig. 1(b) - (f) are roofs with one or more slopes allowing rain or snow to run off easily. Complex roofs can be combined by simpler ones, as shown in Fig. 1(g) - (j). For instance, the roof in Fig.1 (h) is actually generated by two crossing gable roofs in Fig. 1(b).

Each 3D roof can be decomposed into a series of weight-supporting compositions and affiliated compositions. Fig. 2 shows the side view of a gable roof with columns and beams supporting its weight. Affiliated entities, such as rafters, gables, fascias, cornices, eaves and soffits, are used as decorative or functional compositions.

From above analysis, we find that 3D roof reconstruction can actually be divided into two parts: weight-supporting entities reconstruction and affiliated entities reconstruction. Once the position and altitude of each weight-supporting entity are reconstructed from a 2D drawing, affiliated entities can be correspondingly generated according to their usages. Therefore, our target is to reconstruct the weight-supporting entities.

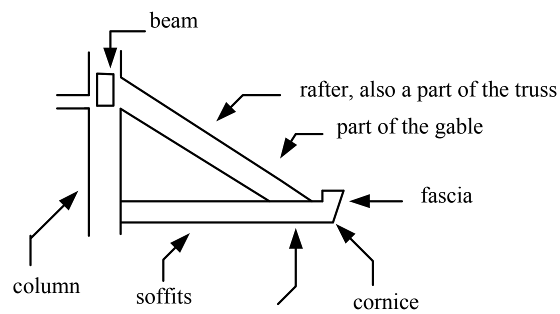

Fig. 2 Internal compositions of a gable roof.

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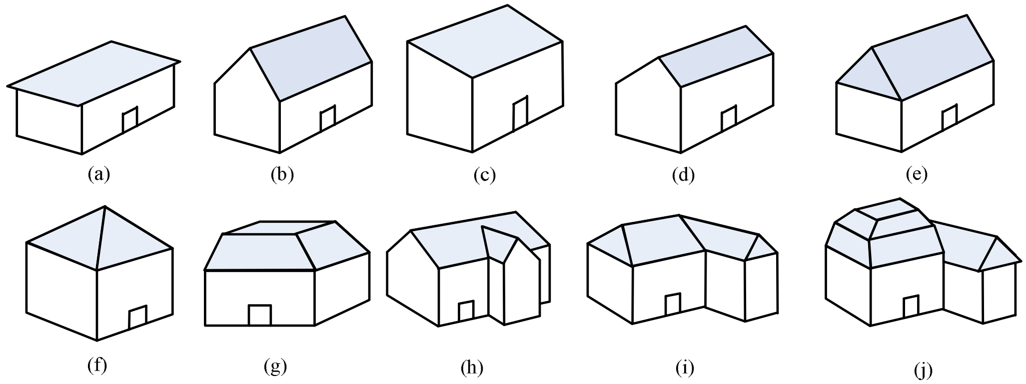

Fig. 1 Typical 3D roofs. (a) a flat roof, (b) a gable roof, (c) a shed roof, (d) a saltbox roof, (e) a hipped roof, (f) a pyramid roof, (g) a mansard roof, (h) a cross gable roof, (i) a cross hipped roof, and (j) a complex composed roof.

3. Semi-automatic roof reconstruction

We use the following steps to reconstruct 3D roof entities: 1) recognition of weight-supporting entities to obtain their 2D contours and semantic relations, and 2) interactive 3D roofs reconstruction by designating altitudes to the recognized results in an efficient way.

3.1. Recognition of 2D plane roof drawings

We take the recognition of weight-supporting entities and extraction of their semantic relations as the first step for 3D roof reconstruction. In our previous research, we illustrated the method to recognize different architectural entities from 2D drawings [9]. Fig.3 (a) shows a simplified plane drawing of an example pyramid roof, where 5 columns (from C_1 to C_5) and 11 beams (from B_1 to B_{11}) are found. The semantic relations among the recognized entities can be described by the *Component Relation Graph* (*CSG*) [9] (see Fig. 3(b)). A *CSG* here is composed of nodes and segments, where a segment represents a beam/wall entity since it is always drawn by a group of parallel lines, while a node has two possibilities: 1) an overhang end of a beam/wall entity which is supported by another column or beam/wall entity, and 2) an intersection in the middle of a beam/wall entity. For instance, $node_i$ is an overhang node for seg_j, while it is an intersection node for seg_k as shown in Fig. 3(b).

3.2. Pulling-pushing reconstruction operations

Next, we reconstruct roofs by directly "pulling" or "pushing" the nodes in *CSG* in an interactive way. The difficulty is how to efficiently reconstruct various types of 3D results directly from 2D graphs. For instance, we need find out how to generate the two possible models in Fig. 4(b) and Fig. 4(c) from Fig. 4(a) in an easy way.

For this target, we first give the following definitions:

1. **Initial level** (l_i): all the nodes in a given *CSG* share the same initial level only decided by the floor number of the roof plane drawing.
2. **Pulling/pushing level** (l_p): the level assigned by a pulling or pushing operation.
3. **Incremental level** (l_c): $l_c = l_p - l_i$. ($l_c > 0$) implies a pulling operation and ($l_c < 0$) implies a pushing operation.
4. **Invariable node**: the node whose incremental level l_c is always 0 and its altitude never changes during pulling or pushing operations.
5. **Warped node**: the node whose incremental level l_c changes along with the others.
6. **Straight-kept segment**: the segment always holding to be straight. When pulling or pushing one node on a straight-kept segment, the other nodes vary with it to keep the segment straight.
7. **Active segment**: the segment on which any node is pulled or pushed. The pulled/pushed node is named as a **key node**.
8. **Passive segment**: the rest segments except for the active ones.

Then we reconstruct 3D roofs from *CSG* in the following steps:

1) Assign l_c for a key node $node_i$ on an active segment;
2) Designate attributes for all the active or passive segments containing $node_i$ if necessary;
3) Automatically recalculate the levels for all the nodes on the active or passive segments containing $node_i$;
4) Repeat step 1-3 until node levels never vary.

We use the following rules to automatically recalculate the levels of the other related nodes after designating the new level to a key node.

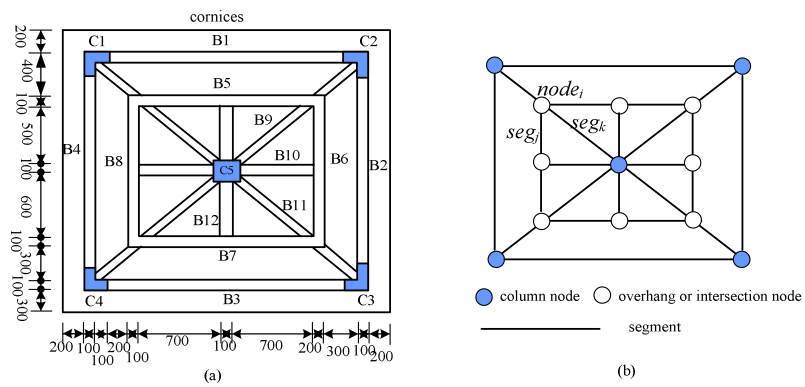

Fig. 3 The recognized results from a plane roof drawing. (a) a simplified plane roof drawing composed of columns and beams, and (b) the recognized results, where the columns or the intersections of the beams in Fig. 3(a) are represented by nodes, while the beams are represented by segments to simplify their semantic relations.

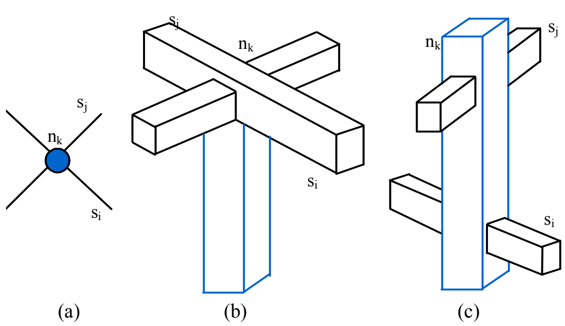

Fig. 4 Different 3D reconstruction results from the same plane roof drawing. (a) a recognized *CSG*, (b) one reconstructed column and two connected beams, (c) one reconstructed column and two disconnect beams.

3.2.1. Pulling-pushing one single node on a segment

When pulling or pushing one single node on a given segment, we first initialize all the rest nodes except for the key one as follows:

Rule 1: Set all the overhang node(s) as invariable ones;

Rule 2: Set the rest nodes as warped ones.

Then we reconstruct a straight-kept segment or a bent one by pulling or pushing the key node on it as follows:

Rule 3: By pulling or pushing one of the overhang node (Fig. 5(a)), a straight segment used in a shed roof is reconstructed (Fig. 5(b));

Rule 4: By pulling or pushing an intersection node (Fig. 5(c)), a bent segment used in a gable or saltbox roof is reconstructed (Fig. 5(d)).

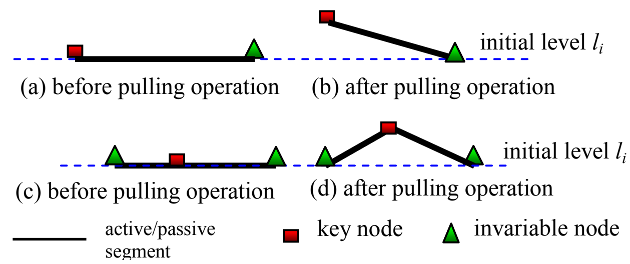

Fig. 5 Pulling or pushing one single node on a segment.

3.2.2. Pulling-pushing two or more nodes on a segment

When pulling or pushing two or more nodes on a given segment, we first similarly initialize the node attributes using rule 1 and rule 2. Then we reconstruct it as follows:

Rule 5: By pulling or pushing two or more intersections (Fig. 6(a)), a bent segment used in a mansard roof is reconstructed (Fig. 6(b));

Rule 6: By pulling or pushing the two overhang nodes (Fig. 6(c)), a straight segment used in a shed roof is reconstructed (Fig. 6(d));

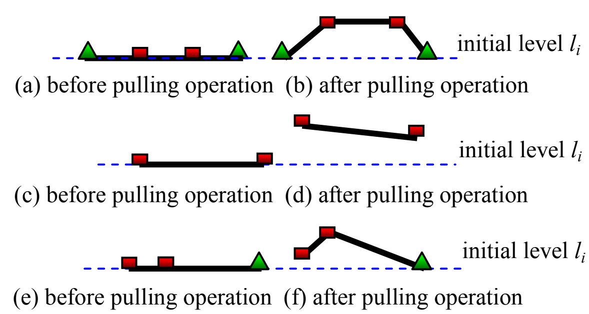

Fig. 6 Pulling or pushing two or more overhang or intersection nodes on a segment.

Rule 7: By pulling or pushing one overhang node and one or more intersection nodes (Fig. 6(e)), a bent segment used in a saltbox roof is reconstructed (Fig. 6(f)).

Rule 8: By pulling or pushing two or more intersection nodes and designating an overhang node as a variable one (Fig. 7(a)), a bent segment used in a mansard roof is reconstructed (Fig. 7(b)).

Rule 9: By pulling or pushing two or more intersection nodes, designating an intersection node as an invariable one and designating an overhang node as a variable one (Fig. 7(c)), a bent segment used in a mansard roof is reconstructed (Fig. 7(d)).

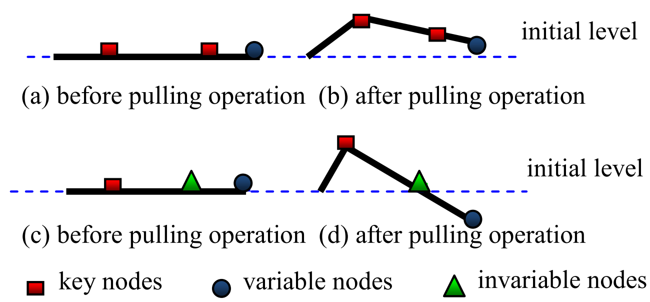

Fig. 7 Pulling or pushing two or more overhang or intersection nodes and designating variable ones on a segment.

3.3. Roof reconstruction examples

Fig. 8 illustrates some roof reconstruction examples using the mentioned definitions and rules.

In the first three examples (Fig. 8(a) – Fig. 8(c), Fig. 8(d) – Fig. 8(f), and Fig. 8(g) – Fig. 8(i)), we reconstruct roofs by directly pulling key nodes. For instance, a gable roof (see Fig. 8(c)) is reconstructed by pulling the two key nodes in Fig. 8(b) recognized from the simplified plane drawing in Fig. 8(a). Similarly, a hipped roof and a mansard roof can be reconstructed.

Fig. 8(j) - Fig. 8(l) show an example by first defining invariable nodes and then pulling key nodes. Fig. 8(j) is a simplified plane drawing of a cross gable roof. To reconstruct the left part of the cross gable roof, we first define the two key nodes 3 and 4 (see Fig. 8(k)) and then pull these two nodes to reconstruct the left part. To reconstruct its right part, we need first define the nodes 6 and 7 as invariable ones and then pull the other two key nodes 1 and 2. The reconstructed result is shown in Fig. 8(l). Note that if 6 and 7 are not defined as invariable ones, the segment containing 9, 6, 5, 7, 8 will be reconstructed as shape "V" since their levels vary with that of 5.

Fig. 8(m) - Fig. 8(p) shows another roof reconstruction example by defining straight-kept segments. Fig. 8(m) shows the plane drawing of a cross hipped roof. By designating the two straight-kept segments N_a-N_b and N_b-N_c and designating the invariable node N_b (see Fig. 8(n)), we reconstruct a cross hipped roof (Fig. 8(o)) by pulling the three key nodes. Fig. 8(p) gives its internal structure.

4. Conclusions

This paper proposed a semi-automatic 3D roof reconstruction method composed of the following two steps: automatic recognition of 2D plane drawings and interactively "pulling" or "pushing" the recognized results. Typical types of 3D roofs can be reconstructed in an efficient way. Further research includes 3D reconstruction of more complicated roof structures and the affiliated compositions.

Acknowledgements

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5. References

[1] D. Dori, K. Tombre, "From Engineering drawings to 3D CAD models: are we ready now? ", *Computer-Aided Design*, 1995;24(4):243-254.

[2] IV. Nagendra, UG G, "3D Objects from 2D Orthographic view – A Survey", *Computer Graphics*, 1998;12(1):111-114.

[3] MA W, G. Markowsky, "Fleshing out projects", *IBM Journal of Research & Development*, 1981;25(6):934-954.

[4] H. Masuda, M. Numao, "A Cell-based Approach for Generating Solid Objects from Orthographic Projections", *Computer-Aided Design*,1997;29(3):177-187.

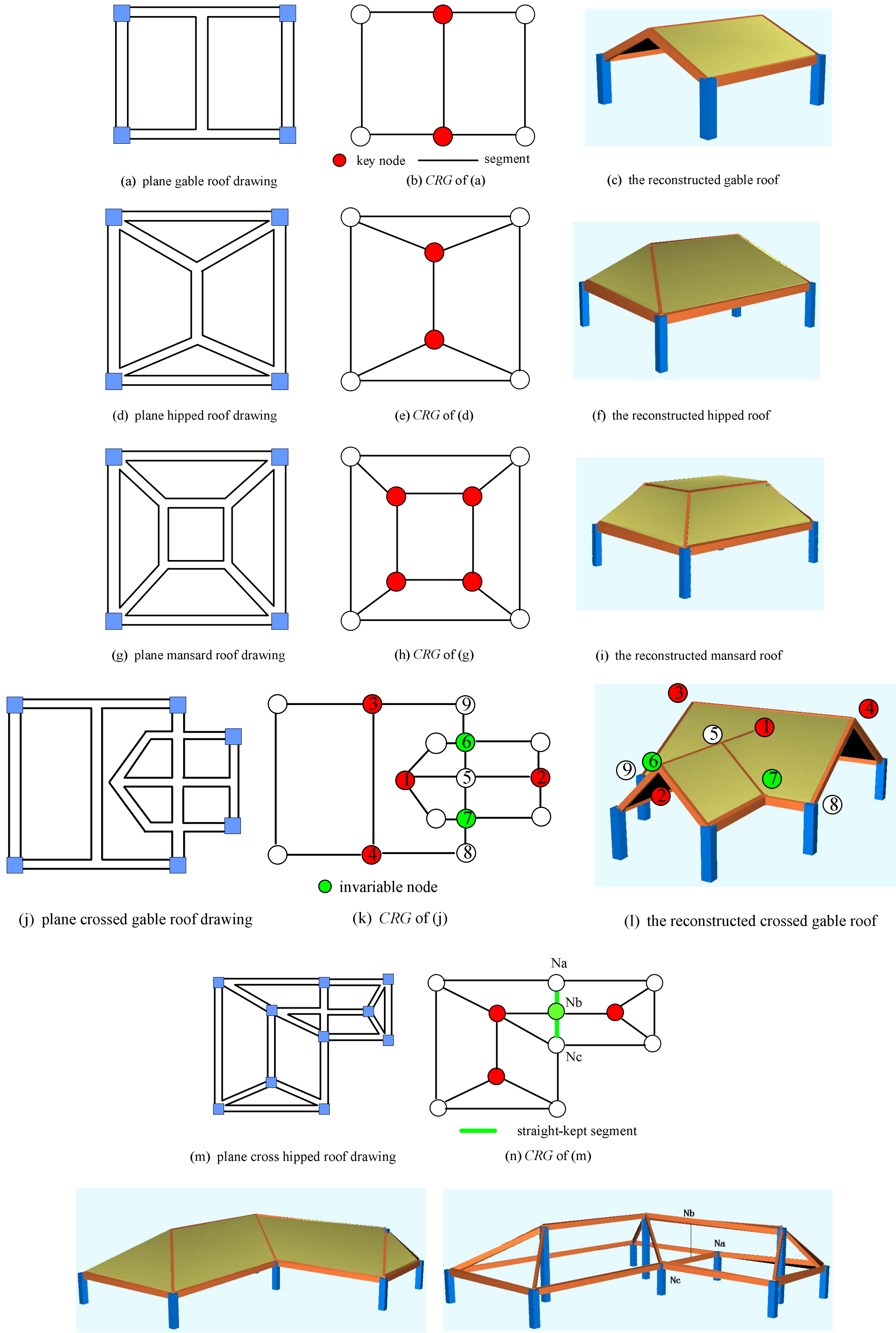
[5] S. Ablameyko, V. Bereishik, A. Gorelik, S. Medvedev, "Reconstruction of 3D Object Models from Vectorised Engineering Drawings", *Pattern Analysis & Applications*, 2002;5(1):2-14.

[6] C. Ah-Soon, K. Tombre, "Variations on the Analysis of Architectural Drawings", *Proceedings of the Fourth International Conference on Document Analysis and Recognition*, 1997:1:347-351.

[7] R. Lewis, C. Séquin, "Generation of 3D Building Models from 2D Architectural Plans", *Computer-Aided Design*,1998;30(10):765-779.

[8] T. Lu, C.L. Tai, L. Bao, F. Su, S.J. Cai. "3D Reconstruction of detailed buildings from architectural drawings", *Computer-Aided Design and Applications*, 2005;2(1-4):527-536.

[9] T. Lu, C.L. Tai, F. Su, S.J. Cai. "A new recognition model for electronic architectural drawings", *Computer-Aided Design*, 2005;37(10):1053-1069.



(a) plane gable roof drawing (b) *CRG* of (a) (c) the reconstructed gable roof

(d) plane hipped roof drawing (e) *CRG* of (d) (f) the reconstructed hipped roof

(g) plane mansard roof drawing (h) *CRG* of (g) (i) the reconstructed mansard roof

(j) plane crossed gable roof drawing (k) *CRG* of (j) (l) the reconstructed crossed gable roof

(m) plane cross hipped roof drawing (n) *CRG* of (m)

(o) the reconstructed cross hipped roof (p) internal of the reconstructed cross hipped roof

Fig. 8 Roof reconstruction examples.