Automatic Semantic Labelling of 3D Buildings Based on Geometric and Topological Information

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Abstract. The lack of suitable information in 3D models of buildings and cities is still a strong limitation for the increasing number of applications requiring the 3D data. The latter are often obtained from acquisition or modeling processes during which the geometry is well preserved, but the topological and semantic information are lost. We present a new approach to enrich a purely geometric model with topological information. The reconstructed topology combined to the geometry is helpful to several operations like guided building simplification, model correction, etc. In this work we recover the semantic information based on a propagation approach guided by heuristic rules. All the process is automatic and designed such that any user can bring and customize as many rules as needed to supervise the semantic labelling. As example we propose few rules applied to both Building Information Models (BIM) and 3D Geometric Information Systems (GIS) data.

Keywords: Topology; Semantic; Combinatorial Maps; CityGML; BIM.

1 Introduction

Recent progress in the massive 3D acquisition area (photogrammetry, laser scanning, ...) made possible the generation of dense and precise 3D data going from the representation of a simple building to a whole city. It is the case for example in the GIS field where urban model data are obtained thanks to airborne laser points and images, or terrestrial laser scanning. But indoor details of the building are rarely available from such acquisition methods. In the other hand, CAAD[1] tools allow architects to produce models with high level of indoor and outdoor details, leading to very realistic models, used in BIM fields for instance. Several useful applications rely on such type of data to contribute to human well-being (navigation, simulation, etc), involving many different areas of expertise. Due to the different needs of those fields, purely geometric model is clearly insufficient for most of the applications, that require to exchange topological and semantic information to perform analysis.

To face this problem, two standards arise from both GIS and BIM domains, that are respectively the CityGML format from the Open Geospatial Consortium [20] and the Building Smart IFC format [8]. They are mainly semantic-oriented standards, allowing to store all kind of information useful to describe

[1] Computer-Aided Architectural Design

buildings, ranging from their intrinsic components up to their environment. They are more and more used and aim at being central for all expert fields involved in a construction or renovation project. Unfortunately the information stored in such standards are often poor in practice. Indeed only the geometry is more or less completely informed, leading to lack of important information. Thus topology and semantic need to be retrieved to complete information available in the standards.

We propose a new method based on a propagation approach directed by heuristic rules to retrieve the semantic information of the building components (wall, roof, openings, etc). Starting from the geometry of a model presented as a bunch of unconnected polygons, we use the Combinatorial Map (C-Map) data structure [9,18] to subdivide the model into structured cells with their topological relationships. The latter in addition to the geometric properties available allow us to define the rules and to design the propagation process of the semantic labelling among all the components of the model. We tested our method on both BIM and GIS models.

After a study of previous works on this topic, we will first describe the topological formalism behind the method. The semantic labelling based on that topology and the geometry will be then detailed for BIM and GIS data, and the results of the method will be analyzed. Finally a global discussion including the outlooks will be held to propose potential improvement of the work.

2 Related Works

2.1 Existing Approaches

3D Building modelling is an extensively research topic, and even more during this last decade in which major interest grown up from private institutes and local authorities regarding 3D urban models. This is due to the interesting range of applications they offer, e.g. building renovation, cultural heritage preserving, navigation maps, etc. Depending on the applications targeted, the proposed methods in the literature focus more on topological, semantic or geometric aspect of the model.

An important amount of work have been dedicated to topology in both BIM and GIS domains, because topological relationships between the components of the model are essential for the data consistency [15] and also crucial for simulation processes [4, 28]. Several works addressed topological query operations issues [6, 12], while others proposed data structures to handle building models. Combinatorial data structures appear to be very relevant as topological model for buildings. Generalized Maps (G-Maps) were used to represent the topology of indoor scenes reconstructed from 2D plans [16] and to optimize simulation processes (visualization, lighting, etc) [14]. Thomsen et al. [27] also used G-Maps to take advantage of their generic properties from lower to higher dimensions, in addition to cell-tuple structures. The authors proposed the construction of topological model from city data but the process involves considerable user interaction for consistency. Boguslawski and Gold introduced the Dual Half-Edge

(DHE) data structure for modelling building interior using cell complexes [5]. Globally, combinatorial data structures are equivalent in their main skills. As DHE and G-Maps, C-Map offers iterators to navigate through any entity of the cell complex and attributes can be associated to any cell of any dimension.

Methods allowing feature identification and semantic information recovering in building and urban models also take an important place as the two major standards (IFC and CityGML) are mostly semantic-oriented. But the data available in those standards are not always consistent [10]. Furthermore, many techniques were developed to extract particular features depending on the type and the data quality. Bauer et al. [3] extracted features on façades point cloud while Pu and Vosselman [21] proposed the extraction of features like walls, doors, windows, etc, from terrestrial laser scanning. Thiemann and Sester [26] proposed a partitioning of complex building model based on an adaptation of the algorithm of Ribelles et al. [22]. The model is intersected with planes of its boundaries to detect features interpreted using a rule-based decision tree. The method does not seem to deal with indoor details. More recently, Boulch et al. [7] introduced a semantic labelling method on CAD building models based on a constrained attribute grammar with geometry specific predicates on planar 3D primitives. The method deals mainly with surface-oriented models (the identified components are not volumes).

Regarding the geometry, two main topics are leading the researches in urban modelling: building generalization and model repairing. As a 3D city model has a huge amount of polygons, it is of major interest to reduce them for interactive visualization and navigation purposes. This is the reason why many works addresses the building simplification issues [13, 23, 25]. In the other hand, it is quite common to meet invalid geometries and aberrations in city models. This is usually not a problem for visualization, but it is a serious drawback for most of the applications that need to rely on valid geometry to proceed to credible calculations. In that sense, recent works are oriented in repairing common polygons errors in GIS [1, 17].

In our work, the geometry is assumed to be clean enough. And contrary to the methods in the literature, our approach is generic, deals with indoor as well as outdoor details and needs no prior information regarding the model, except its geometry. This can be done thanks to the formalism behind C-Maps that we use as data structure to model the topology. From that topology, in addition to the geometry, we define heuristic rules to semantically identify building components.

2.2 Combinatorial Maps

A C-Map is an edge-centered data structure representing the spatial subdivision of an object of any dimension, by a cellular decomposition. In 3D it describes an object by the mean of 0-cells (vertices), 1-cells (edges), 2-cells (faces) and 3-cells (volumes). The basic element of a C-Map is a *dart* which is a part of an oriented edge plus a part of each *incident* i-cell (two cells are incident if one belongs to the boundary of the other). The darts are linked between them thanks to β_i links,

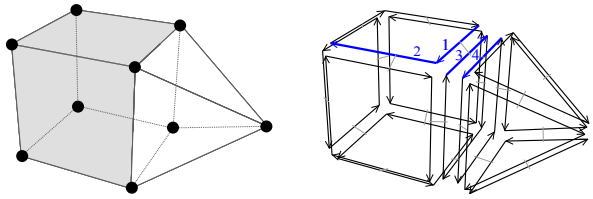


Fig. 1. Example of a 3D C-Map. Left: a 3D object made of two volumes adjacent along a face (at the basis of the pyramid). Right: the corresponding C-Map, with darts represented by arrows (sometimes numbers). Darts 1 and 2 belong to the same face and darts 1, 2 and 3 belong to the same volume.

allowing the representation of the incidence and *adjacency* relationships binding the cells (two i-cells are adjacent if they share a common incident $(i-1)$-cell).

More precisely, a 3D C-Map is $C = (D, \beta_1, \beta_2, \beta_3)$, with D a finite set of darts, β_1 a *partial permutation*[2] on D, β_2 and β_3 *partial involutions*[3] on D. β_1 of a dart $d \in D$ returns dart $d' \in D$ belonging to the next edge, the same face and the same volume than d. Similarly, β_2 of a dart d gives dart d'' belonging to the other face, the same edge and the same volume than d. Finally, $\beta_3(d)$ returns dart d''' that belongs to the other volume, the same edge and the same face than d. Some constraints are defined on the C-Map to guarantee its topological validity (see [9,18] for more details). Partial permutation and partial involutions allow to represent objects with boundaries: when a dart d is such that $\beta_i(d) = \varnothing$, d is said i-free.

As an illustration, in Fig. 1, we have $\beta_1(1) = 2$, where both darts 1 and 2 belong to the top face of the cube volume. $\beta_2(1) = 3$, where darts 1 and 3 describe the same edge, but belong to different faces of the cube. $\beta_3(3) = 4$ with 3 being a dart of a face of the cube while 4 is a dart of the adjacent volume (the pyramid), and both 3 and 4 describe the same edge and the same face.

The previous notions allow us to describe any cell as a set of darts. For a 3D C-Map, 2-cell(d) is the set of darts that can be reached from a given dart d and using β_1 and β_3 as many times as possible; 3-cell(d) is the set of darts that can be reached from a given dart d and using β_1 and β_2 as many times as possible. Intuitively, since β_i allows to consider the other i-cell containing a given dart, if we use all the β's links except β_i we obtain all the darts belonging to a same i-cell. In Fig. 1-right, the face separating the cube and the pyramid is the set of 8 darts containing darts 3 and 4, and the volume describing the cube is the set of 24 darts containing darts 1, 2 and 3.

A C-Map allows to associate information to any cell through *attributes*. We will denote i-attr(d) the attribute of the i-cell(d). The attributes are used to

[2] A partial permutation f on a set D is a bijection from $D \cup \{\varnothing\}$ to $D \cup \{\varnothing\}$ with $f(\varnothing) = \varnothing$ and s.t. $\forall x, y \in D$, $f(x) = f(y) \neq \varnothing \Rightarrow x \neq y$.

[3] A partial involution g on a set D is a partial permutation on D satisfying $g(x) \neq \varnothing \Rightarrow g(g(x)) = x$.

store the geometry by associating to each 0-cell of the C-Map a 3D point in $\mathbf{R}^3$. Such C-Map, with 3D points associated to the 0-cells is called a Linear Cell Complex (LCC), and is the data-structure used in this work.

In [11], a method allowing to reconstruct the topological description of a building with a 3D LCC is introduced. Authors used this description as basic data structure to extract automatically the different level of details of the building.

3 Topological Formalism

Our approach is targeting two types of building data: BIM and GIS. A fundamental difference between them comes up from their different acquisition methods. The latter lead GIS models to be mainly based on the representation of observable surfaces of the buildings while BIM models are made of volumetric primitives representing the building components [19]. Here we discuss how LCCs are used to describe each type of data and to recover their topology. These descriptions will be used in the next section to propose the heuristic rules of our automatic semantic labelling algorithm.

3.1 BIM models

BIM data are resulting from designers that use CAAD tools to model buildings. They are often very detailed and offer indoor and outdoor details. Despite a visual differentiation between the components of the model, their information are rarely explicitly available and the geometry of the whole model is often stored as a polygonal mesh, with a list of vertices, and face sequences. The topological reconstruction gives us a component-based decomposition of such building model with a full connection network between all the components (see Fig. 2).

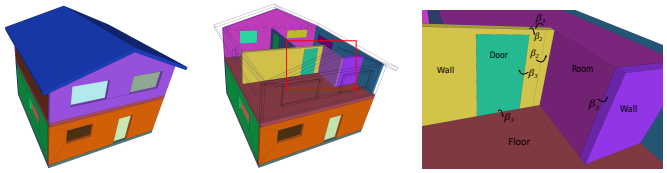


Fig. 2. Component-based topological reconstruction of a BIM model from unconnected 3D polygons. Left: view from outside. Middle: view of the inside components. Right: example of navigation by β_i links, the room volume is filled and one wall is hidden for visual purpose. Each color represents one 3-cell.

Each volume of the 3D LCC represents a meaningful building component (wall, floor, ceiling, roof, door, window, room, etc). Note that rooms are also described in the topological description by property of the reconstruction (a

room can be seen as an air volume). This is particularly useful for navigation algorithms where we can retrieve all the volumes adjacent to a room (walls, openings, floors and ceilings). The semantic of each component is stored by associating to each volume of the LCC a 3-attribute containing an *id* giving the type of the component. No more additional information is required by our method.

By properties of LCCs, volumes are subdivided into faces describing the different parts of each component. For example a wall could be described by six faces describing a cuboid. Faces and volumes can be traversed thanks to darts and the different β's links. For example given a dart d belonging to a wall, we can iterate through all the darts of the wall by using a depth search algorithm starting from d and using all the possible β_1 and β_2 links. For each dart d' of the wall, $\beta_3(d')$ (when it exists) gives a dart of a building component adjacent to the current wall. Thanks to the topological description, different algorithms can be proposed to navigate through the parts of the building (see Fig. 2-right).

3.2 GIS models

The GIS data are often obtained by aerial or terrestrial laser scanning, photogrammetry or stereovision methods mainly resulting in 3D surface-based models. The acquisition schemes provide more or less dense point cloud that are processed and meshed to obtain polygonal surfaces. In this work, our data are resulting from aerial techniques sharpened to produce roof and ground surfaces and were extracted from CityGML files. The walls are obtained by extruding faces from the roof boundaries to the ground. This leads to models with average level of details (LoD2) [20].

The topological reconstruction gives us here a surfacic description of the buildings since interiors are not described (see Fig. 3-left). For this reason, contrary to BIM models, meaningful information is now associated with faces. Each face of the 3D LCC represents a part of a building, which could be wall, roof or ground. The semantic is here stored by associating to each face of the LCC a 2-attribute containing an *id* giving the type of the component.

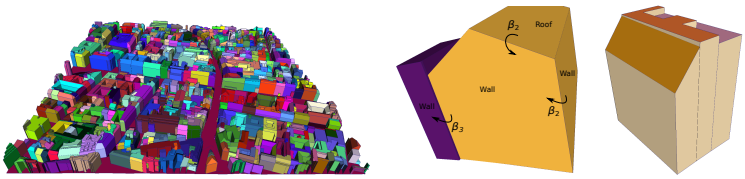


Fig. 3. Left: resulting topological reconstruction on a sample of 3D city model of Paris. Middle: navigation from one cell to another using the β_i links. Right: Example of a building complex composed of 3 volumes.

Note that a building correspond at least to a volume, and at most to a set of connected volumes. Indeed, separated roofs can lead to a volume break-up of the same building. We call *building complexes* such set of volumes supposed to represent a single building (see Fig. 3-right) and we address this issue in the next section by proceeding to a volume clustering followed by a façade extraction.

In the topological description, given a dart d we iterate through all the edges incident to the face F containing d by using β_1 links. For each dart d' of F, $\beta_2(d')$ gives a dart of a face adjacent to F. Thanks to these links, given a face F describing a roof, we can obtain one dart for each face adjacent to F which is a wall or another roof (see Fig. 3-middle).

4 Automatic Semantic Labelling

In this section we introduce an automatic semantic labelling process that entirely relies on heuristic rules based on the geometric properties and on the topological description of BIM and GIS. For each type of data, key features are first detected and labelled, then a propagation approach is adopted to label the remaining cells of the LCC.

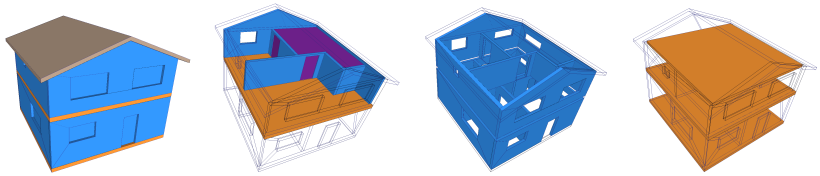
The flexibility of the method allows to define as much rules as desired. The strength of our approach is to allow to mix geometrical and topological criteria. This is of significant importance as any expert of any field can define proper rules for general or specific building features. As an illustration of the method, we introduce few rules applied to our data to label common building features. The different propagation approaches will be detailed for BIM and GIS data. In both cases, we consider the 3D LCC $C = (D, \beta_1, \beta_2, \beta_3)$ resulting from the topological reconstruction.

For orientation purpose, we will consider the vector $\boldsymbol{Z}$ as the height axis of the coordinate system of the LCC. A 2-cell is *horizontal* if its normal vector $\boldsymbol{N}$ is collinear to $\boldsymbol{Z}$, and *vertical* if $\boldsymbol{N}$ is perpendicular to $\boldsymbol{Z}$. *null* is used to express non-existent property, e.g. a 3-cell without semantic attribute.

4.1 BIM Models

Our goal is to semantically identify the main components of the building (walls, floors, openings, roof and façade) among the 3-cells of C. We assume to deal with building models in which there is no furniture and where only building component are described, there is no volume describing air spaces. During the topological reconstruction, the air volumes are obtained by duplicating 3-free faces (i.e. faces separating a building component and an air space). The volume with maximal size is the exterior shell of the building (which is not kept in the LCC); all the other air volumes are rooms and are labelled with 3-attr(d) ="room". Those 3-cells will be the starting point of our semantic labelling propagation. All other volumes are initialized with 3-attr(d) ="null".

Walls and floors identification: The rooms are directly linked to the walls and the floors surrounding them. We consider all the darts $d \in D$ s.t. 3-attr(d) =“null” and 3-attr($\beta_3(d)$) =“room”.
(1) 3-attr(d) =“wall” if 2-cell(d) is *vertical*;
(2) 3-attr(d) =“floor” if 2-cell(d) is *horizontal*.



(a) (b) (c) (d)

Fig. 4. (a) Result of the walls (blue) and floors (orange) labelling (the unlabelled volumes take random color). (b) Room volume (purple) used to propagate semantic information to surrounding volumes. (c) The identified walls. (d) The identified floors.

Fig. 4 illustrates the result on a simple model. Rule (1) defined for the walls involves that all the volumes having β_3 links with the *vertical* faces of the rooms are categorized as walls. Thus even doors and windows will initially be labelled as so (Fig. 4(a)). But thanks to the propagation approach, this will be corrected in the following steps. Note that with rule (2), floors and ceilings are not differentiated.

Windows and doors identification: At this step of the process, some volumes identified as walls are in fact openings components (doors, windows). Assuming that any door or window of the building has top and bottom surfaces containing at least one horizontal face each and is embedded in a wall volume, we can define adapted rules. We consider each dart $d \in D$ s.t. 3-attr(d) =“wall”. Let d_t and d_b two darts s.t. 2-cell(d_t) and 2-cell(d_b) are the top and bottom *horizontal* faces of 3-cell(d).
(3) 3-attr(d) =“window” if 3-attr($\beta_3(d_t)$) = 3-attr($\beta_3(d_b)$) =“wall”;
(4) 3-attr(d) =“door” if 3-attr($\beta_3(d_t)$) =“wall” and 3-attr($\beta_3(d_b)$) =“floor”.

The volumes are considered as windows if they have their top and bottom faces linked by β_3 to a wall volume (rule (3)), while they are considered as doors if their bottom faces are linked to a floor and their top faces are linked to a wall (rule (4)). Of course several specific configurations could occur in a building model. But these rules are enough in the case of classical models such that the one given in Fig. 5.

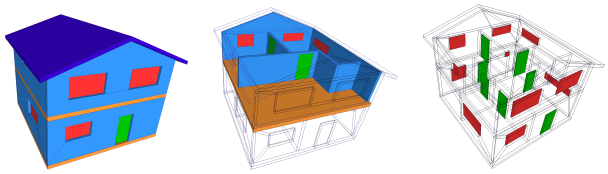
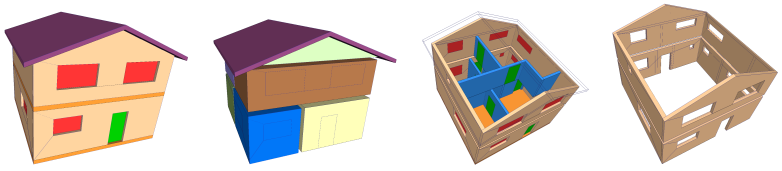


Fig. 5. Left: result of the windows (red) and doors (green) labelling (the unlabelled volumes take random color). Middle: some example of walls used to detect openings. Right: all the identified openings in the model.

Roof and façade identification: For several applications the notion of interior and exterior is of major interest. This is why the façade is a significant information to label, so as the roof, that is actually part of the façade, but here we will label them differently. Considering our topological representation, the room volumes are supposed to fill all the spaces lying inside the building model. Thus any 3-cell is linked by β_3 either to a room or to a component. We denote by D_{hi} the set of darts containing one dart for each 3-cell which is a highest room of C along $\boldsymbol{Z}$. These properties allows to propose the following rules. We consider each dart d, and denote d_t (resp. d_b) one dart of the top (resp. bottom) *horizontal* face of 3-cell(d).

(5) 3-attr(d) =“façade” if 3-attr(d) =“wall” and $\exists d' \in$ 3-cell(d) s.t. d' is 3-free;

(6) 3-attr(d) =“roof” $\big($if 3-attr(d) =“floor”, d_t is 3-free and $\exists d_{hi} \in D_{hi}$ s.t. $\beta_3(d_b) \in$ 3-cell(d_{hi}) (flat roofs)$\big)$;
or $\big($if 3-attr(d) =“null”, $\exists d' \in$ 3-cell(d) s.t. d' is 3-free and $\exists d'' \in$ 3-cell(d), $\exists d_{hi} \in D_{hi}$ s.t. $\beta_3(d'') \in$ 3-cell(d_{hi}) (tilted roofs)$\big)$.



(a) (b) (c) (d)

Fig. 6. (a) Result of the roof (violet) and façade (beige) labelling. (b) The roof linked to the highest room (light green). (c) Difference between the inside and outside walls. (d) All the identified walls of the façade.

Rule (5) addresses the walls because they are the only components considered for the façade here (see Fig. 6(d)). But this could be modified easily to include other features. The first part of rule (6) regarding the roof considers that a floor

with its top face in the exterior and its bottom face linked to one highest room is a flat roof. But if the concerned 3-cell is part of a pitched roof, no rule defined so far would recognize it, leaving the volume with no semantic attribute (*null*). Thus if such volume has one dart linked by β_3 to one highest room in addition to a 3-free dart, it will be considered as part of a pitched roof by the second part of rule (6) (see Fig. 6(b)). All roofs of a building may not be necessarily at the highest height. Thus for particular cases other rules must be defined.

4.2 GIS Models

In a LoD2 city model there are only few building features interesting to identify: roofs, walls, ground and façades. Our goal here is to extract those features from the model and to label them using the LCC attributes. In a first step, we will identify the 2-cells to consider as roofs before spreading the semantic labelling to walls and ground faces.

Roofs and walls: Contrary to BIMs, at the beginning of this process, $\forall d \in D$, 2-attr(d) = "null". The heuristic rule necessary to identify the roofs is simply based on normal orientation checking. Once identified, the roofs will help us to recognize and label the walls. Let $\boldsymbol{N_d}$ be the normal of 2-cell(d) and $\alpha = angle(\boldsymbol{N_d}, \boldsymbol{Z})$.

(7) 2-attr(d) ="roof" if $|\alpha| \in [0, \frac{\pi}{4}]$;

(8) 2-attr(d) ="wall" $\big($if 2-attr(d) ="null" and 2-attr($\beta_2(d)$) ="roof"$\big)$;
or $\big($if 2-attr($\beta_2(d)$) ="wall" and $|\alpha| = \frac{\pi}{2}\big)$.

In rule (7), the range chosen for α allows to cover flat roofs as well as pitched ones, as illustrated in Fig. 7. It is a criterion dependent of the model, since the inclination of pitched roofs depends on many parameters (geographic position, surrounding environment, local weather, etc). In the other hand, it involves that even the ground surface is labelled as roof, but this will be fixed in the following steps. First part of rule (8) tells that any unlabelled face linked to a roof by β_2 represents a wall. This is a consistent heuristic on our data due to their production process (see Sect. 3.2). Second part of rule (8) is necessary just in case some coplanar faces are not merged, resulting in several 2-cells describing the same planar surface. Because of this, some vertical 2-cells might be unlabelled while their neighbors by β_2 are recognized as walls. Figure 7 shows what we get after this step, i.e a model in which all the 2-cells are either labelled as roof or as wall. We can then proceed to the ground surface labelling.

Ground surface: The ground can be intuitively described as the biggest surface (in area) with the lowest height in the model. It is necessary to several simulation processes (e.g flood simulation). It is unlikely to have a flat and regular ground surface (except for roads or particular installations), thus the ground can be composed of several faces in the model. At this level of the semantic labelling process, those ground patches are tagged as roofs, so we propose rules to correct them. We consider each dart d s.t. 2-attr(d) ="roof".

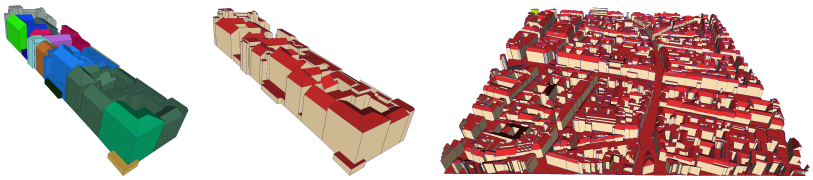


Fig. 7. Example of roofs (in red) and walls (in beige) semantic labelling from building volumes of LoD2. Left: result of the topological reconstruction. Middle: semantic labelling of the left image. Right: semantic labelling on the model shown in Fig. 3. At this step, the ground surface is also marked as a roof.

(9) 2-attr(d) ="ground" $\big($if 2-cell(d) is the biggest face with the lowest height$\big)$;
or $\big($if $\exists d' \in$ 2-cell(d) s.t. 2-attr($\beta_2(d)$) ="ground"$\big)$.

The first part of rule (9) is dependent of the coplanar face merging process applied during the topological reconstruction. Otherwise the assumption of the biggest face will not be usable. The second part of rule (9) is a direct consequence of the first part, since once the main 2-cell of the ground is found, the information is spread to its proper neighbors. Figure 8 shows the result on a district. Thanks to the semantic information, the ground can be isolated from the rest of the model. At the end of this step, we have now enough information to proceed to the façade extraction.

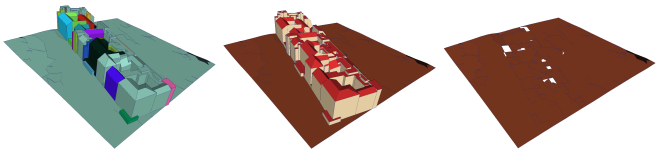
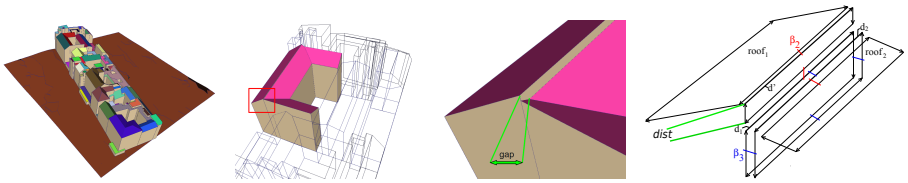


Fig. 8. Ground surface identification. The image at the left shows the resulting topological representation of the initial model. The middle image illustrates the roofs, walls and ground identification and the right image is the isolated ground patch (holes are due to missing polygons on the input data).

Façade Extraction: The term façade is used to define the exterior side of a building, not only the front. With GIS data, the main issue is first to identify building complexes properly. The initial data does not contain enough information to allow a perfect clustering of the volumes in building complexes. But with the enhanced LCC model, rules can be defined to group 3-cells. Initially, each 3-cell belongs to its own cluster. Considering two clusters c_1 and c_2:
(10) c_1 and c_2 are merged if $\exists d_1 \in c_1$ and $\exists d_2 \in c_2$ s.t. $\beta_3(d_1) = d_2$;

2-attr($\beta_2(d_2)$) ="roof", 2-attr($\beta_2(d_1)$) ="wall";
and $\exists d' \in$ 2-cell($\beta_2(d_1)$) s.t. 2-attr($\beta_2(d')$) ="roof";
and if the height of 2-cell($\beta_2(d_1)$) $\leq$ *dist*,
where *dist* is a predefined distance.



(a) (b) (c) (d)

Fig. 9. (a) Initial clustering of building volumes, each roof color represent a building complex. (b) and (c) Example of gap between two building, detected thanks to the rule. (d) C-Map representation of (c), to illustrate the rule.

This rule allows to group the buildings when roofs are separated by a small gap which could result from either inaccuracy issues during the data acquisition, or architectural design (as illustrated in Fig. 9).

The gap is filled by the wall face extruded from the higher roof ending up in two 3-cells sharing a common face. The rule describes the topological configuration of the wall above that common face and just consists in measuring its height to compare it to a threshold named *dist* in the rule definition (Fig. 9(d)). Such gaps can be detected and the corresponding volumes clustered in the same building complex. A proper threshold can directly help to solve the case of buildings designed with roofs of different height levels.

Now the façade is identified on the formed building complexes. Similarly to BIM models, the notion of exterior (represented by 3-free darts) and interior is used to identify the proper cells. Each dart d is considered:

(11) 2-attr(d) ="façade" $\big($if d is 3-free$\big)$;
or $\big($if d and $\beta_3(d)$ do not belong to the same cluster$\big)$.

Those two simple rules are enough to access to all the 2-cells of the façade. As illustrated in Fig. 10 where a building complex made of three volumes is presented, extracting the façade means identifying the inner faces of the complex. Once they are known, it is possible to remove them. They are characterized by two darts linked by β_3 and belonging to the same building complex.

5 Implementation details and Limitations

All our algorithms based on C-Maps/LCC were implemented using the Computational Geometry Algorithm Library (CGAL [24]) and we used the Open Asset

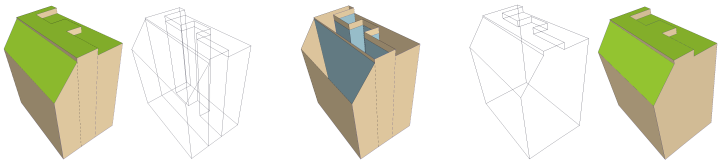


Fig. 10. Façade extraction on building complex. Left: the original complex (roof in green) in filled and wire-frame version. Middle: the faces inside that are not part of the façade (in blue). Right: the resulting façade.

Import Library (Assimp [2]) to parse the input data (Collada, Obj, etc). The complete process of semantic labelling, including the topological reconstruction and façade extraction were executed in 1.02s on the BIM model in Fig. 2 (836 faces), 1.23s on the GIS model in Fig. 7 - left (1481 faces), 6.19s on the model in Fig. 8 (4352 faces) and 224.65s on the model of Fig. 7-right (55378 faces). Note that several optimizations could speed up our method. The computer used is a laptop with an Intel Core i7-2760QM 2.40 GHz and 8GiB of RAM.

An important constraint of the method we presented relies on the quality of the input data. It is well known that 3D models resulting from GIS acquisition methods are subject to common artifacts (gaps, holes, polygon permeation, etc). While our approach is strongly related to topology, those defects lead to topological errors limiting the capacities of the automatic semantic labelling. BIM models are not safer since they are resulting from architects who mainly care about the visual aspect only. This leads to models in which it is frequent to meet inconsistent geometries, created just for hiding or producing a visual effect. In the other hand, the richness of the details is still very challenging for automatic feature identification. Although we apply pre-processing algorithms (e.g coplanar faces simplification, ill faces correction or removal, points adjustment, etc) before the topological reconstruction and the semantic labelling, we do not pretend to proceed to model correction. But solving the correctness issues of the data will be probably of great benefit for all the applications using them. We also adopt a margin of error ϵ for all the computations, as the numerical data of the models are exposed to rounding issues. Depending on the fixed ϵ the method can fail where the errors are significant (e.g important gap between two faces supposed to share an edge).

6 Conclusion and Outlooks

We presented a framework to automatically retrieve the semantic information of a building or a city model thanks to the combination of geometry and topology. Starting from the geometry described by a bunch of unconnected polygons, the topological links between the vertices, the edges, the faces and the volumes are reconstructed first. Then heuristic rules are proposed based on the relationships between the components. Features of interest are labelled through a propagation

approach. The strength of the approach is in its adaptability to BIM or GIS data in addition to its flexibility in creating proper rules for the models. The method were tested on synthetic and real data, and offered interesting results.

Some improvements can still be brought to the method to perform better results. For example it would be interesting to combine cadastre information to the GIS data for an easier and accurate identification of building complexes. In the other hand, it can be of major interest to set a correction tool to heal the input data often containing inconsistent information. We also plan to allow users to locally apply in a model the rules they define and to investigate the automatic semantic labelling of more detailed models, e.g LoD3 for GIS or furnished model for BIM. There is still a long way to go to get a fully automatic and reliable interpretation of the different building elements, but we believe that our method is a promising approach.

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