The Conversion from CityGML to 3D Property Units

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Key words: 3D Property Unit, CityGML, 3D Cadastre, Data Conversion

SUMMARY

Due to the fast growth of building construction technology and increasing demands on the efficient use of land, human living space are expanded from on the surface to above and under the earth surface. It raises the need for three dimentional (3D) cadastral by realizing that the current cadastral system based on 2D is not appropriate to reflect the precise representation. 3D property unit is the basic unit of 3D cadastral similar to the parcel in 2D cadastral. Data source of 3D property units under the circumstance of 3D Cadastre is still a challenge. This paper provides the framework and the workflow of the conversion from CityGML to 3D cadastral. According to the requirement of the semantics and geometry of 3D cadastral objects, the mapping rule and correspondence between CityGML and 3D property unit will be calibrated. It is needed to extract the geometry data from CityGML for the construction of 3D volumetric units for 3D properties based on the mapping rules. Furthermore, test cases are implemented to validate the conversion method.

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1. INTRODUCTION

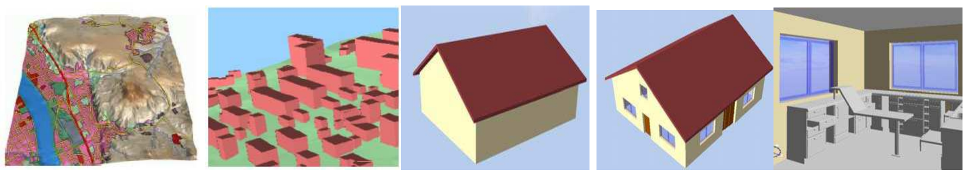
Due to the increasing demand on the efficient use of land, it has been expanded in multi-level which are above and under the surface. The two-dimension cadastre cannot reflect the situation of three-dimension land utilization. So 3D cadastre is urgent to be systematically researched to solve the cadastral management issues in three-dimension exploitation and utilization of land (Ying, 2011; Shi, 2013). In the "Real Right Law of the People's Republic of China" (2007), the 136th article points out that the use right of construction land may be created separately on the surface or above or under the land. It provides the legal foundation for t3D cadastre. With the development of 3D cadastral, how to obtain 3D cadastral data is becoming a major problem. Traditional ways to get 3D cadastre data such as laser scanning, surveying, photogrammetric measurements (Isikdag et al, 2009) are costing and time consuming. CityGML is a field of 3D data in which a vast amount of high-value data is created. By bridging the gap between the fields of 3D cadastre and CityGML, a new data source can become available with an unprecedented amount of detail.

This paper is organized as follows: firstly, the necessity of the research is stated and background information about 3D property unit and CityGML is given. The section 3 covers the mapping rule between CityGML properties. Then the details of the conversion methodology are elaborated in Section 3 and test cases are implemented in Section 4. Finally, further improvements and open questions are pointed out with concluding remarks.

2. THE SEMANTIC ASSOCIATION BETWEEN 3D PROPERTY UNIT AND CITYGML

Three-dimensional cadastre is a cadastre which registers and gives insight into rights and restrictions not only on 2D parcels but on three-dimensional property units. Besides the juridical and factual situations above and under the surface, 3D cadastre emphasizes the 3D boundaries and 3D volumes of 3D property units and their spatial relationships. Under the new circumstance of 3D cadastre, a 2D parcel is no longer the basic unit, and it is replaced by 3D property unit. 3D property unit is a closed and independent spatial domain which is bounded by ownership boundaries or surface (Guo, 2012; Ying, 2011). 3D property unit which has fixed geospatial location and shape, usually uses 3D geometry to represent its scope and the space-related rights, and the later are explained by the relevant laws and regulations.

CityGML(OGC City Geography Markup Language) is a common information model from semantic organization architecture for the representation of 3D urban objects. It defines the classes and relations for most relevant topographic objects in cities and regional models with respect to their geometrical, topological, semantical and appearance properties (Gröger, 2012; Baig, 2013). Both semantic information and geometry information are included in CityGML data. The semantic information describes the attributes and relationships between objects and, more importantly, the semantic is associate with the corresponding geometry information. The geometry information mainly describes the spatial locations and scopes of the objects by 2D faces normally. The semantic and geometry information are consistent with each other. For example, if a wall in the building has two windows and a door in semantic information, then for the geometry, the wall has two windows and a door (Sun, 2011; Goetz, 2013). Based on this relationship, the research objects of this paper are the objects under the label of cityObjectMember which is relevant with building information (Yi, 2010), and other information such as vegetation and transportation can be excluded.



LoD0 LoD1 LoD2 LoD3 LoD4

Figure 1. The five Levels of Details (LOD) defined by CityGML for building models

However, in terms of the demands of 3D cadastral, there is still a large gap between the geometry data in CityGML data and 3D property unit. CityGML focuses on the appearances and the shapes of the landscape and buildings with physical realities. They are all at the stage of visualization of the external physical surface of the city objects. These data have not reached the requirements of 3D property unit which is the basic unit of city management and applications (Guo,2012). Although 3D property unit and CityGML are similar to some extent, the specific geometric data of them are in a tremendous difference. So making the correspondense rules of the data model between them and finding the needed geometry data to be handled further are the keys to convert CityGML data to 3D property unit.

3D property unit has basic triple elements: the semantic and ownership information, spatial information and 3R (Rights, Responsibilities, Restricts). The semantic and ownership information can be obtained when registered; spatial information refers to the geographic boundaries in the building, construction and other real estate. More importantly, for 3D property unit, its geometry is a volumetric space bounding by boundary faces. The mainly described objects in CityGML data are buildings with different Levels of Details (LoDs) and precisions. CityGML supports different LoDs. The building models at LoDs differ in the complexity and granularity of the geometric representation (Figure 1). In terms of constructing 3D property unit, CityGML LoD0 has no buildings, only 2D parcels are relevant to 3D cadastre. CityGML is organized by semantic objects. In CityGML LoD1, the building is a box bounded by serveral 2D fascades, which is similar to the shape of the simple 3D property unit. the roof of the building is descriped in CityGML LoD2 , detail wall and roof structures, door and windows are given in CityGML LoD3 .CityGML LoD3 is extended in CityGML LoD4 by adding interior structures like room, stairs and furniture (Kolbe, 2009). LoD2-LoD3 are more related to the real estate and 3D cadastre. The semantic objects that are related with 3D property unit in CityGML are shown in table1. The conversion from

CityGML to 3D property unit has the benefit of allowing the re-use of the captured high-value building information without being time-consuming and costing.

Table1. The semantic objects related with 3D property unit in CityGML

Objects	LoD1	LoD2	LoD3	LoD4
BuildingFurniture	--	--	--	x
CeilingSurface	--	--	--	√
ClosureSurface	--	--	--	√
Door	--	--	√	x
FloorSurface	--	--	--	√
GroundSurface	√	√	√	√
IntBuildingInstallation	--	--	--	x
InteriorWallSurface	--	--	--	x
RoofSurface	√	√	√	√
Room	--	--	--	x
RoomInstallation	--	--	x	x
WallSurface	√	√	√	√
Window	--	--	x	x
the objects except buildings	x	x	x	x

(Note: "--" indicate that there are no such objects in this LoD, "√" indicates that this object is included in this LoD and needed for constructing 3D property unit, "x" indicates that this object is not used to construct 3D property unit.)

3. THE EXTRACTION AND CONVERSION of CityGML GEOMETRICS

The method of conversion between CityGML data and 3D property unit is based on two steps: semantic requirement and transformation, geometry transformation. Since the classes defined in CityGML are different from the 3D property unit, the two transformations cannot be implemented separately. The extraction of geometrics from CityGML is based on the semantic requirements of 3D cadastre, and the CityGML objects are presented by the certain geometrics that can be used for constructing 3D property unit. The overview of the conversion workflow is provided in Figure 2.

In the following sections, we use CityGML LoD3 as the examples to deliver the details of the converstion from CityGML to 3D property unit.

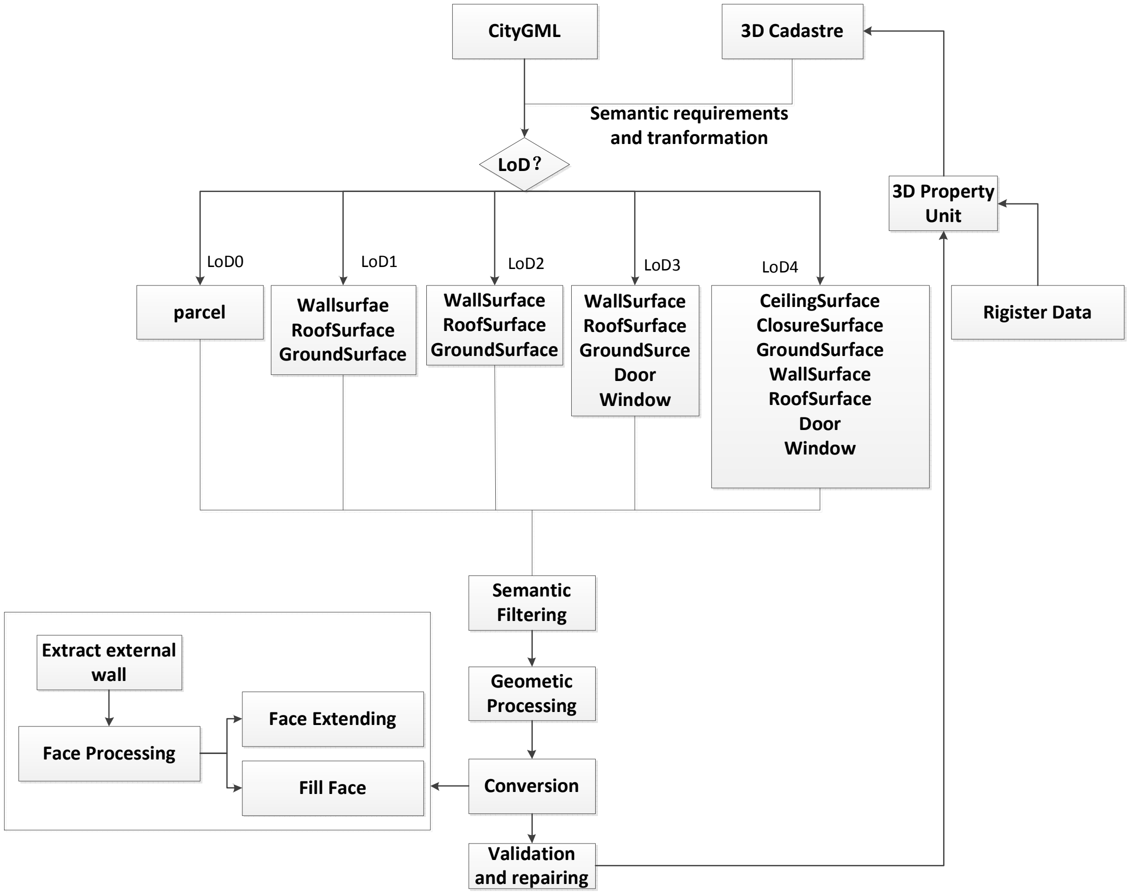


Figure 2. The overview of the conversion methodology

3.1 Filtering of CityGML objects based on semantics

There are too many classes defined in CityGML, but considering the paper is output-driven, only several classes are used for 3D property unit as Table 1 listed. Furniture, for example, is not relevant to 3D property unit. Furthermore, city objects that do not have geometry or are not part of the building can be ignored. Filtering these objects leaves only those objects in CityGML which are meaningful to construct 3D property unit. The object filter with CityGML data based on semantics still follows the rules of CityGML. Door or window are still single object grouped by multiple faces, but the color and texture information will have no relations for 3D property unit. Also, some city objects, such as BuildingInstallation and BuildingFurniture, which are useless for constructing 3D property unit are cleared. The filtering result of deleting the doors and windows of LoD3 is shown in Figure 3. Although the doors and windows are deleted, there are still some information reserved to record that these doors and windows will be merged with the walls as boundary face (stated later in Section) to menifest the shape of 3D property unit.

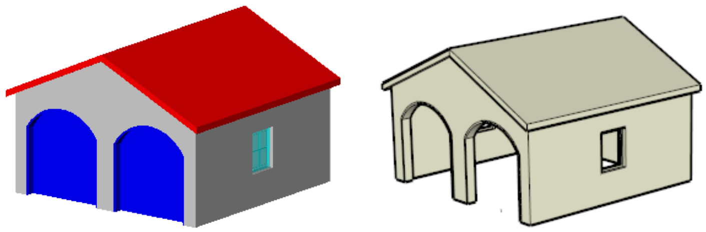


Figure 3.Filtering of CityGML objects based on semantics objects

3.2 The processing of CityGML geometry and topology

The class Opening in CityGML is used to describing doors and windows in outer or inner boundary surfaces like walls and roofs. Openings only exist in models of CityGML LoD3 or LoD4. Each Opening is associate with a MultiSurface geometry, such as WallSurface or RoofSurface. If a wall has a window, there will be new faces to store the door and the window. Based on the data organization rule of CityGML, when deleting the door or window, there will be holes in the wall (Figure 4a, 4b). Actually if a wall has a window, this wall will be described as an exterior ring and an interior ring (Figure 4a). Repairing the hole in this step in 3D space is complicated and prone to error. So we extract the exterior wall firstly, then data processing can be transfered to 2D space.

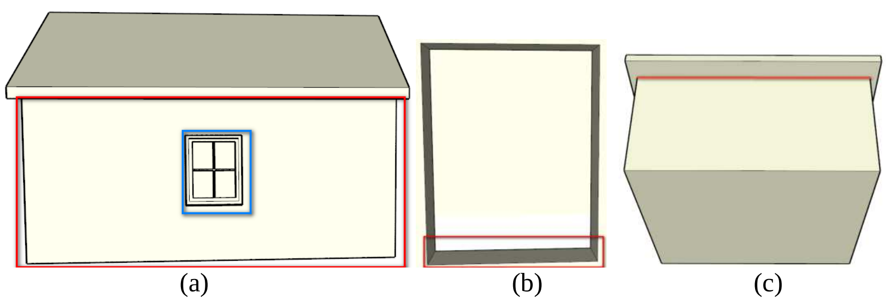


Figure 4. The result of deleting window and the new edges

To extract the exterior wall, we need to obtain the topology information of the geometry data firstly. CityGML provides the ralationship information in semantics (for example, a wall has a window), but we cannot know the topology information based on the geometry. When converted to 3D property unit the objects in CityGML data will become to be one expressed by closed 3D solid with topology information. Therefore, during the conversion processing, the geometrics from CityGML data are needed to be re-combinated. So new edges are introduced to complete the topological connectivity, if not, some geometric features, such as the wall and the roof, will lose their associations. As shown in Figure 4c, the association of the wall and the roof is described by semantics, in this case, new edges are needed to be introduced to guarantee the connectivity between the wall and the roof. After this step, the semantic objects in CityGML will be re-united into a 3D geometry, then we can extract the exterior wall.

As shown in Figure 5a and 5b, the way this paper used to extract exterior surface faces is: 1) chose an arbitrary point within the building; 2) draw the vertical ray of the wall from that internal point, then two intersection points will be produced, one with the exterior wall and the other with the interior wall; 3). the point that is farther from the internal point is located on the exterior wall. Figure 5 shows the serial shapes of extracting exterior wall with schematic diagram and geometric data respectively. After extracting the exterior surface faces, the next data processing will be similar with 2D space. The doors and the windows will be 2D rings, and it will be easy to repair.

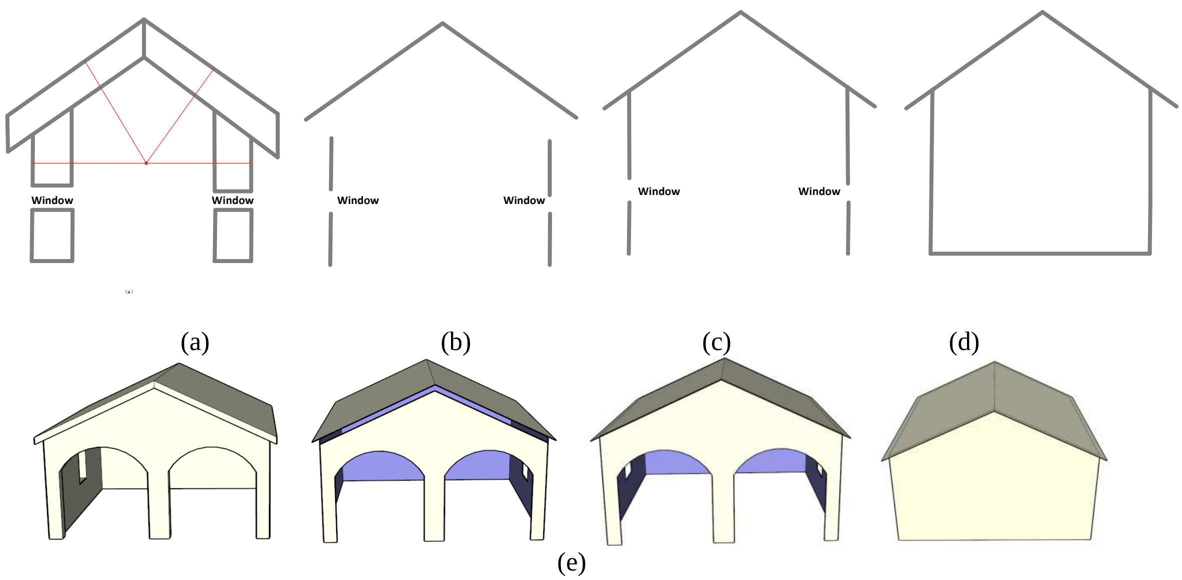


Figure 5. Serial shapes of extracting the exterior surface faces

3.3 The repairing and validation of 3D geometry

CityGML is a model with rich semantic information. In the processing of extraction and conversion, it will produce a large number of redundant data. When two walls are converted to faces that connected with each other, it will produce redundant edges; Extracting the exterior wall will result disconnection of the wall and roof; The roof may result in dangling faces; There may be 2D rings due to the exist of door and window (Figure 5). These all can be validated and repaired using the method in (Van Oostereom et al, 2005; Ledoux et al, 2014) Serial shapes of repairing 3D geometry is shown in Figure 6. After the extraction of the outer surface faces (Figure 6a), dangling faces are deleted (Figure 6b), then the bottom bounding face are added to delimit the boundary (Figure 6c). As the doors and windows are also used as the boundaries within the walls, the hole shapes that represent the doors and windows are filled and stitched (Figure 6d). As a result, a 3D volume to represent the 3D property unit is constructed (Figure 6e).

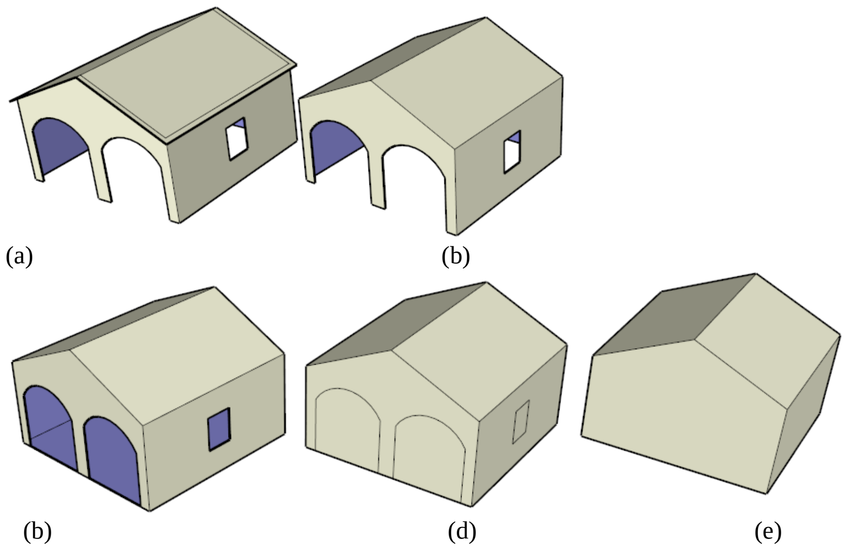


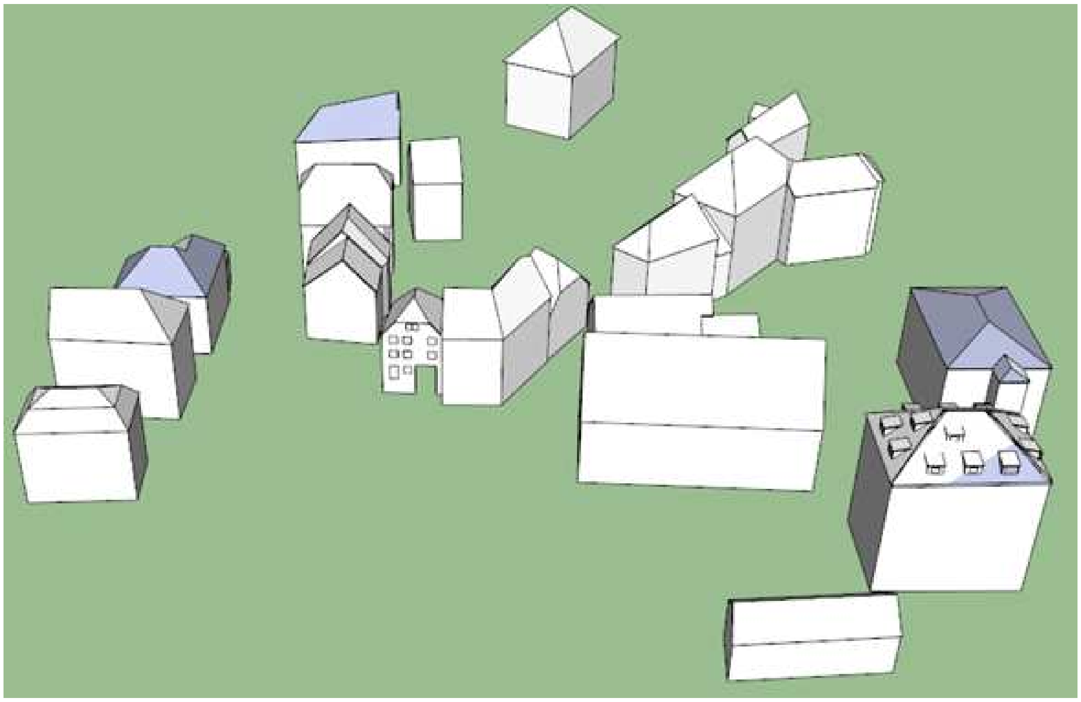
Figure 6. Workflow diagram of Repair 3D Geometry

3.4 The construction of 3D property unit

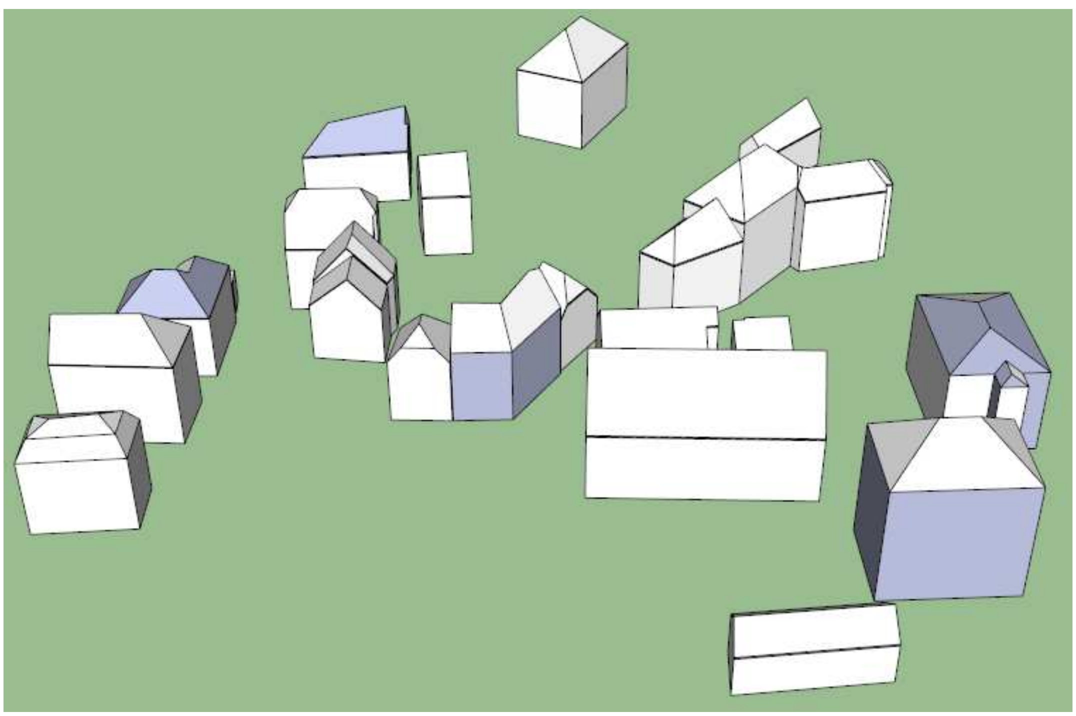
Actually after the proceeding and repairing the data only has spatial geometric information for 3D property unit. Due to the conversion from CityGML data to 3D property unit is for practical applications, some semantic information such as ownership information and 3Rs is needed to produce a complete object of 3D property unit. This information can be obtained when registered.

4. IMPLEMENTATION AND EXPERIMENTAL RESULTS

The main research question of this paper is whether it is possible to do the conversion to support the requirements from 3D cadastre. A complete conversion methodology has been developed, and the real data is tested. The original data of CityGML LoD3 has 5637 faces (Figure 7a), and after simplification and conversion, and the result data has 22 3D geometric volumes which are constuted by 338 faces.



(a)



(b)

Figure 7.The comparison of the results and the original data

5. CONCLUSION

Accurate three-dimensional geometry spatial data and rich semantic information are needed for the development of 3D cadastre. Traditional methods such as laser scanning, surveying, photogrammetric measurements are time-consuming and costing which seriously hindered the development of 3D cadastre. CityGML is a common semantic information model for the representation of 3D urban objects that can be shared over different application. This paper provides the framework and workflow of the conversion from CityGML data to 3D cadastral unit with the test of city data of CityGML LoD3. The method in this paper can make supplementary for the traditional method to collect 3D data for 3D cadastre. It will be a great data source for a wide range of 3D city modeling and spatial analysis.

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