A WORKFLOW FOR THE SEMI-AUTOMATIC GENERATION OF LOW COST 3D CITY MODELS

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ABSTRACT

This paper presents a workflow for semi-automatic generation of 3D cities that addresses two challenges; generate low cost multiresolution models and provide semantic information. To achieve this, different free data sources are integrated in a CityGML model. CityGML is a standard data model approved by the OGC (Open Geospatial Consortium). The steps followed in this workflow are: access to information, pre-process information, adapt the data model, process information and generate the CityGML file. The result of this workflow is the generation of a realistic and multiresolution 3D city model.

1. INTRODUCTION

The generation of 3D city models with a high level of detail requires an investment of hours and high costs (Döllner et al., 2006a). There are multiple data acquisition technologies for creating 3D cities as laser scanning, photogrammetry, modelling tools, etc. as explained in (Limp et al., 2010). It is also necessary to complete the 3D model with additional alphanumeric information that provides some intelligence to the model, beyond a three-dimensional representation of geometric elements (Gröger and Plümer, 2012).

A 3D city model allows representing geo-referenced spatial urban data (Döllner et al., 2006a)(Döllner et al., 2006b). A 3D city model consists of terrain, buildings, land use, vegetation and roads, among others. The main feature of these models is to store all information of a city in a single data model, which eases the use and interoperability of the same.

These models allow presenting, handling and managing urban data that can then be used in different applications such as disaster management, urban planning, rehabilitation, traffic planning, security, telecommunications, navigation, and tourism (Over et al., 2010a)(Egusquiza et al., 2014).

Generating realistic 3D cities in various resolutions is one of the challenges today. Depending on the level of detail and the technique chosen for the generation, the costs can grow exponentially (Singh et al., 2013).

The main contribution of this paper is the definition and development of a workflow to generate 3D city models from free data sources that can generate a realistic model with multiple resolutions.

2. PREVIOUS WORK

The generation of 3D city models is an issue that is being addressed by many research groups. The main problem is that the process needed to get a realistic and quality model it is time-consuming and expensive (Döllner et al., 2006b)(Döllner et al., 2006a).

One of the possible alternatives for generating 3D city model quickly is by mean of procedural generation (Kelly and McCabe, 2006)(Kelly and McCabe, 2007). The procedural generation is based on generating a large amount of buildings repeating the structure. In procedural generation some parameters can be indicated such as population density, age of buildings or main material. This option is useful for creating 3D virtual cities that can be later incorporated into video games and other applications. The resultant 3D model is very realistic, even if the degree of fidelity is not the most appropriated one. These cities also lack of semantic information.

Another possible alternative is the tool provided by Google, that allows developing 3D model of the city from the contributions made by users. It can be directly visualized the geometry in Google Earth[1]. This approach allows the generation of 3D geometric model of an entire city from user contribution and commitment of local authorities. However it is only a geometric model without semantic information associated.

Another way of generating 3D city models is using LiDAR data (Rottensteiner and Briese, 2002)(Rottensteiner, 2003). Using the point clouds from LiDAR data it is possible to identify and generate buildings in a city. One of the drawbacks of LiDAR data is that is not free available for every municipalities. They also need a large processing and the resultant 3D model has no semantic information.

In 2007 the INSPIRE Directive (Directive, 2007) began at European level, which aims to create a legal framework to establish an infrastructure for spatial information in Europe. Current problems of spatial data are: the lack of information, the data are not properly documented, there is no compatibility between data or services offered, as each country has its own standards and do not enable the reuse of data. INSPIRE will provide the specifications in order to have more reliable data and to make data available to everyone (administrations, businesses and citizens).

For the development of the management activities of a city, it is necessary to have a 3D city model combining geometric information that faithfully represents the reality of their environment; and semantic information, which ensures the intelligence to the 3D model. In the same way, it is important to represent the information using standards or formats commonly adopted in order to ease the exchange of information between different agents or users. Only using free data sources is feasible to develop 3D models of city that represent an accurate model of reality. CityGML

[1] http://maps.google.com/help/maps/citiesin3d/

(Gröger et al., 2012) is a defined standard data model for representing city models that combines semantic and geometric information. Different approaches seek the generation of 3D city models from free data sources.

The data source that gives most of the data and enables the generation of 3D city model comes from the cadastral data. In (Dsilva, 2009) a 3D model is generated by extruding the parcels and then rooftops are added and fachades are textured in order to enhance the realism of the model; and finally the semantic information is added to enrich the model. In (Soriano and García, 2008) they generate a KML files from cadastral information using an attribute that indicates the number of floors. These solutions make it possible to generate 3D city models in a LoD1 (Level of Detail) or LoD2, but the semantic information model is very limited.

Another data source is OpenStreetMap (OSM). OSM is an initiative where the main objective is to create and exchange geographic data freely. In (Over et al., 2010b) OSM data is used to generate a 3D city model. They identified that with the data available currently is possible to generate LoD0 and LoD1, and they identified that more specific parameters are needed to generate a LOD2. In (Rumpler et al., 2012) a 3D city model is generated by combining information from OSM and aerial images. The main drawback of OSM is that, besides the data is entered by non-professional users, there are only certain data areas, and data is not complete.

In order to get models with higher LoD is necessary to use other data sources and technologies. A very interesting approach is based on obtaining a semi-automatic 3D model from images. In (Rodríguez et al., 2013) is done from aerial orthophotography and in (Falkowski et al., 2009) from terrestrial photogrammetry. Both solutions are useful only for geometry, and in the case of terrestrial photogrammetry is useful for insulated objects and simple geometries but exponentially complicated urban environments with a high cost of field work.

Another approach is the generation of 3D models from 3D laser scanning or using 3D modeling tools and CAD. One possible solution is using laser scanning as in (Karabork and Sari, n.d.)(Schwalbe et al., 2005)(Lorenzini, 2009) and adding textures using aerial images. The advantage of 3D scanner is that the quality of the 3D information is very high. However, the volume of data is too large and the models do not contain semantic information. Also using CAD tools, as performed in (Lorenzini, 2009), high precision urban objects are obtained but high cost in terms of money / time are required to generate them. CAD developments is towards IFC models, which include semantic information that is associated with structural elements. There are many articles discussing how to generate a 3D city model from IFC building models (Hijazi et al., 2009) (El-Mekawy and Östman, 2010) (Nagel and Kolbe, 2007). One of the advantages of exporting IFC is that, as IFC is focused on the building, it is possible to export details of buildings (geometric and semantic). Its usefulness lies in creating certain buildings with a high level of detail.

3. PROPOSED SOLUTION

To generate a low cost 3D city model from free data sources, the first step is to specify the data model. In the workflow presented here, CityGML has been chosen for this task. CityGML is an international standard used for the representation, storage and exchange of 3D models of urban objects promoted by the Open Geospatial Consortium (OGC) (Gröger et al., 2012).

The aim of CityGML is to provide a common way to define the basic entities, attributes and relationships that establish a 3D city model, regardless of its scope. Therefore, it allows to consistently represent semantic and thematic properties, taxonomies and aggregations besides the geometry, topology and appearance of objects. A CityGML model is divided into different thematic areas such as: digital terrain models, buildings, vegetation, transportation systems, street furniture.

CityGML can represent graphical information at different levels of detail (Level of Detail - LoD), reusing semantic information. The different levels of detail allow the visualization and analysis of data at different resolutions and scales, depending on the requirements of each application area. Thanks to the 5 LoDs of CityGML it is possible to represent from city scale (Geographic Information System (GIS)) to the field of building and construction elements (Architecture, Engineering and Construction (AEC)) (Döllner and Hagedorn, 2007).

The next step is identifying data sources that can be used to populate the city model. Figure 1 presents the data sources that have been used to generate the 3D city model in this work.

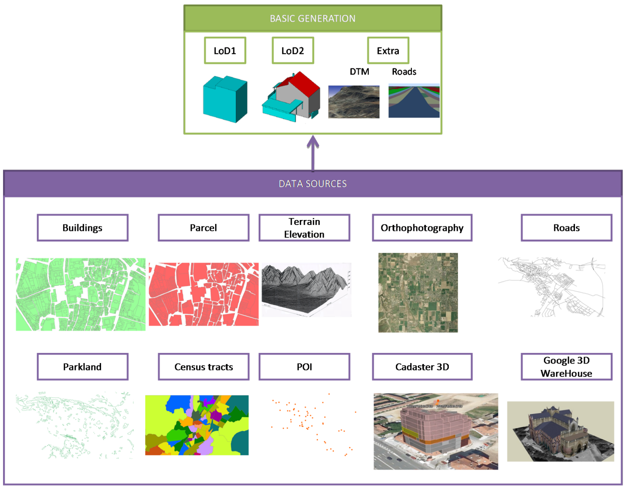

Figure 1: Free data sources identification

A 3D city data model has to store geometric and semantic information. The semantic information can enrich the data model by adding information about urban objects. Semantic information about buildings may include their number of floors, the main construction materials, their uses or information about their owners (Stadler and Kolbe, 2007).

Not all the data sources provide two types of information (geometric and semantic). Figure 2 shows which of the data sources provide geometric information, semantic or both at once.

One of the advantages of CityGML is that, thanks to the LoD, a multi-resolution 3D city model can be generated. Depending on the final application, the required resolution of the 3D model is different. Three levels of resolutions have been differentiated:

- Low: This resolution may represent an entire city and can be generated massively semi automatically. The visualization can be performed on mobile devices.
- Medium: The model has a greater LoD and allows representing a neighborhood, district and historic center. The generation requires more manual work than before. The visualization can be performed on desktop devices with low requirements.

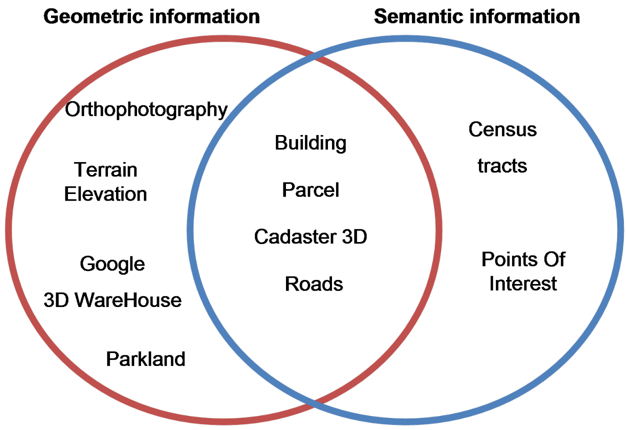

Figure 2: Type of provided information by data sources

- High: The geometric model has a high level of detail and can represent concrete buildings. A lot of manual work is needed in order to generate this model. For visualization a desktop device is necessary with high requirements.

Each of these resolutions can be associated with the defining CityGML LoD. The low resolution and is associated to LoD0 LoD1, medium resolution with LoD2 and high resolution is associated to LoD3 and LoD4.

Table 1 shows the resolution and LoD that can be generated with the different data sources.

Data source	Resolution	LoD
Buildings	Medium	2
Parcel	Low	1
3DWareHouse	Medium	2-3
Cadastre 3D	Medium	2
Roads	Low	0
Terrain	Medium	0-2
Green areas	Low	0
Orthophotography	Medium	0-2

Table 1: Resolution and LoD that can generate each data source

4. DEVELOPMENT

4.1 Data model set up

As a previous step to the generation workflow, the data model has to be set up. As a starting point CityGML data model is going to be used. One of the drawbacks of CityGML is that is too generic and certain thematic information is not represented (van den Brink et al., 2012). It is likely that according to the end user application and requirements, more information than the one represented in the CityGML core will be necessary.

Because of that, a list of needed additional information has to be identified. Once that the information is identified it has to be associated or related to a city object such as: building, wall, window, furniture, road.

After that, needed additional data has to be represented to be part of CityGML. Extension have been designed and developed in CityGML in order to represent the thematic data which is not represented in the core. Different extensions have been designed and published, such as: noise, BIM, Hydro, utility network [2].

[2] [http://www.citygmlwiki.org/

4.2 Generation workflow

The workflow for creating 3D city models from free data sources is presented in Figure 3. This approach first identifies what information is going to be used and how is going to be acceded; after a pre-processing is performed to make a first data cleaning; then information is processed and CityGML files are created and finally all CityGML files are stored in the data model.

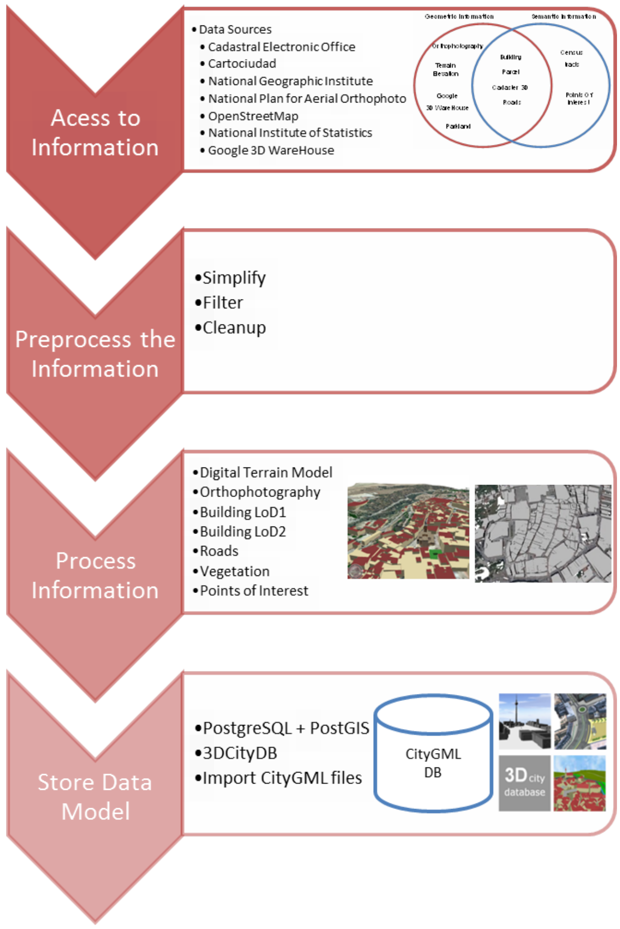

Figure 3: workflow for creating 3D city models from free data sources

Access to information

The first step is to access information from different data sources:

- General Directorate for Cadastre[3]: They provide access to cadastral information in the scope of its competences, by direct access to applications and Web services. The parcels, buildings, green areas and Cadaster 3D buildings has been obtained.

- Cartociudad[4]: Is a project developed by Spain NGI to cross information from the postal service, the cadaster and other sources in order to create a street map covering most Spain cities. Roads and points of interest has been obtained.

- OpenStreetMap[5]: Is a collaborative project to create a free editable map of the world. Points of interest has been obtained.

[3] http://www.sedecatastro.gob.es/
[4] http://www.cartociudad.es/portal/
[5] http://www.openstreetmap.org/

- National Geographic Institute[6]: Which is the national center for geographic information in Spain. The information of the TEM (Terrain Elevation Model) was generated using the Digital Terrain Model (DTM).

- National Plan for Aerial Orthophotography[7]: Which provides, among other photogrammetric products, periodic coverage (from two to four years) of the entire national territory via very high resolution aerial orthophotography. Over DTM an orthophoto has been applied.

- Spanish Statistical Office[8]: Is a independent administrative institution that regulates Statistics activity for state purposes which is the exclusive competence of the State. Alphanumeric information contained in census tracts has been obtained.

- Google 3D Warehouse[9]: Is a free cloud service that allows users to search, upload, download and share 3D models. Models of available buildings has been obtained.

Pre-process the information

The pre-processing phase consists in the following steps:

- Load all the information in the same reference system.
- Perform a cleaning process, eliminating duplicated geometries.
- Perform a filtering process, eliminating geometries without value, such as pool, porch, patios. For LoD1 building generation footprints with less than $36m^2$ are eliminated and for LoD2 building the ones with less than $16m^2$ are eliminated in order to get a more simplified model.
- Perform a filtering process, selecting just the geometries within the interest area
- Simplify the data, getting a less complex model.

Information processing - CityGML file generation

In the information processing phase the workflow presented in Figure 4 is followed.

- Firstly, city model version 1 is created generating buildings in LoD1 using simplified building footprint, LiDAR and DTM. In that process the average height of each building is obtained using LiDAR data. Then each building is created considering that the building has to must be correctly positioned just in the DTM.
- In the city model version 2 buildings in LoD2 are created using detailed building footprint, DTM and LiDAR. A similar step as in the version 1 is used. However the geometry of the footprint is more complex and the geometry of the buildings in LoD2 has to be correctly matched with the previously generated building in LoD1. It is also possible to include external buildings such as Cadastre 3D or Google 3DWareHouse models.
- Finally, in the city model version 3, extra geometry is included like DTM, vegetation, transportation and Points of Interest.

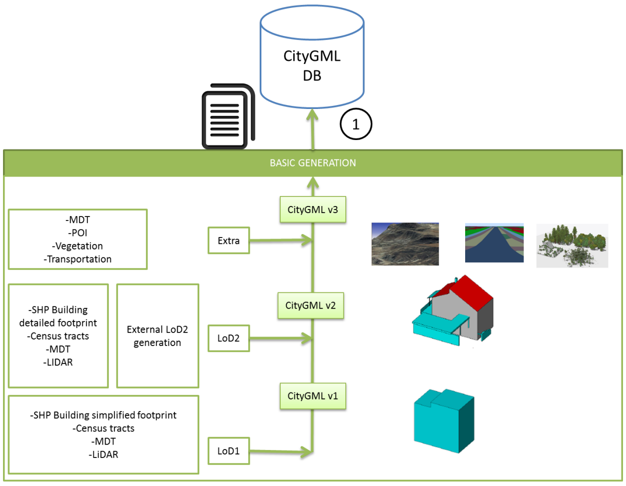

Figure 4: workflow in CityGML file generation process

In the processing phase CityGML files are created. Instead of creating a single CityGML file, which would have a considerable size, a single file is created for each census track and module (buildings, roads, green areas, DTM, etc.).

Store data model

CityGML is intended to represent the semantic and geometric information of city objects. XML is the recommended format to exchange this information but it is not suitable for storing and retrieving complex city models where hundreds or thousands of objects can be involved (Stadler et al., 2009).

Data Model storage is based on the 3D City Database (Kolbe et al., 2013). 3DCityDB is used to represent and store the same information modelled by CityGML. This database implementation is completed with an Importer/Exporter tool in order to process, store and retrieve efficiently and quickly CityGML dataset.

5. PILOT PROJECTS

The workflow has been tested generating the 3D model of three cities, Santiago de Compostela, Segovia and San Sebastian, in Spain.

Even if three cities are in Spain, the cities are in different provinces and the data sources for each city are different. Because of that, the access to information step has been done independently for each city.

- Santiago de Compostela. Santiago de Compostela is a city located in the north-west of Spain with around 100.000 inhabitants, and 18.000 buildings (Figure 5).

- Segovia. Segovia has a population of about 50 thousand inhabitants and covers an area of $160km^2$ and 6500 buildings (Figure 6).

- San Sebastián. San Sebastian is a coastal city in the Basque Country in Spain. An area of $2km^2$ has been generated (Figure 7).

[6]http://www.ign.es
[7]http://www.ign.es/PNOA/
[8]http://www.ine.es/
[9]https://3dwarehouse.sketchup.com/

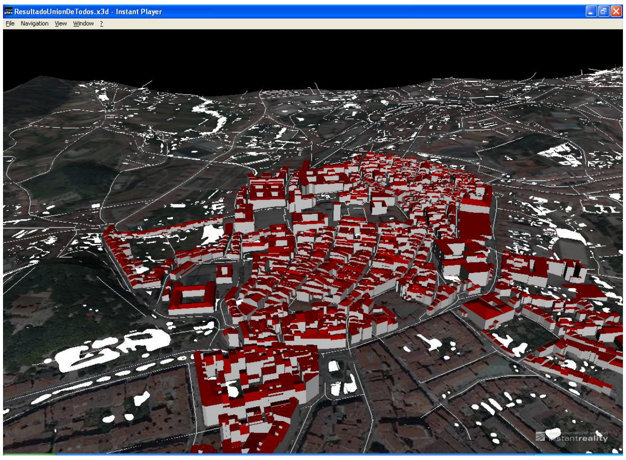

Figure 5: Santiago test case

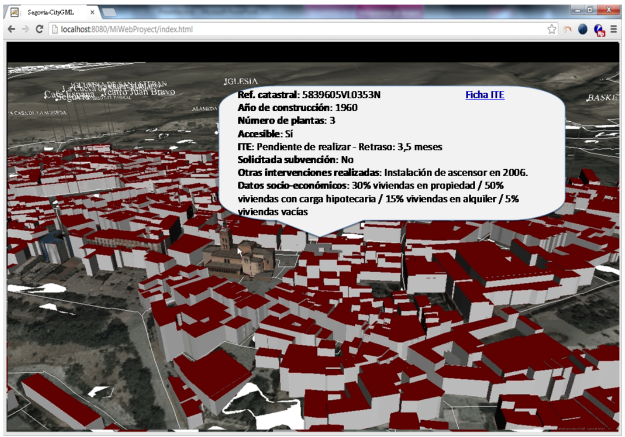

Figure 6: Segovia test case

Figure 7: San Sebastian test case

6. CONCLUSIONS AND FUTURE WORK

Thanks to CityGML it is possible to represent and store semantic and 3D information in the same data model. The interoperability between different software applications and tools related to 3D cities is a problem that now can be reduced through the use of international standards such as CityGML.

Using the developed workflow is possible to generate a 3D city model from free data sources.

The obtained city model it is a realistic model, representing faithfully the reality because the data sources are taken from official organizations that offer high accuracy in data (Electronic Office of Cadastre, Cartociudad, National Geographic Institute, Orthophotography Air National Plan and National Institute of Statistics).

One advantage of the workflow is that it is possible to generate other city elements such as roads, vegetation, POIs; independently and at any time. It is not needed to generate everything at once.

As future work the workflow generation will adapt to the new version of CityGML 2.0. One of the major improvement is the definition of the LoD0, allowing the representation of the footprint of the building. In the same way, more data sources will be identified and integrated in the data model such as CAD files, IFC files. Further progress will be made in the efficient visualization of the geometry of CityGML with semantic information in order to use all the information generated with this workflow.

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