CityGML based Non-photorealistic Visualization Framework for Energy Simulation

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Abstract

Energy consumption simulation is essential for suitable development of a city. However it is costly and inefficient to develop the simulation tools for a city area from scratch, which includes data collection, simulation implementation and results visualization. For every new area or updated data, the whole process has to be performed from start because of the non-standardized input data and visualization method. In this study, we implement a CityGML based platform to unify the input data and establish a standard non-photorealistic visualization strategy to facility the simulation results understanding. Therefore, the relationship between visual variable and 3D generalization is studied to convert the 3D city models from passive, static and sole photorealistic service to positive, dynamic and diversity non photorealistic especially for energy simulation results. It is valuable to deepen the cognition for 3D city models and 3D generalization in both theory and method. Meanwhile, by reducing the data volume and improving the rendering efficiency, this study can be used in other smart city related applications.

Keywords: CityGML, Non-photorealistic visualization, Generalization, Energy Simulation.

1 Introduction

Along with the development of information technology, it is possible to monitor the city in a more detailed level and to generate a Smart City which should create sustainable economic development and high quality of life by excelling in multiple key areas such as economy, mobility, environment, people, living and government. Therefore, it is important to integrate and visualize these complex and large volume of data for expect from social part and public. Considering the status of modern city that contains numerous high building, underground transport system and complex infrastructure, 3D visualization is indispensable.

Considering the complexity of 3D city models and related data, Smart City service in requires supports from generalization of 3D city models, and existing studies mainly focus on photorealistic rendering that generalizes city models from geometric, texture and distribution respectively. However, the 3D city model related application is multitudinous and the data require to visualize is heterogeneous, meanwhile the photorealistic models are expensive to product, complex to rendering, enormous in volume and difficult to share. It is necessary to study non-photorealistic generalization of 3D city models. The bases of non-photorealistic visualization and generalization are visual variables such as geometry, texture and distribution. Therefore, based on theories of modern cartography, computer graphics and data mining, this project proposes a non-photorealistic generalization method for 3D city models using visual variables mapping.

To demonstrate the non-photorealistic visualization framework, we implement the proposed methods into an EU project IntegrCiTy, which is trying to develop an integrated decision-support environment for city planners and energy providers to improve efficiency and resilience of energy supply infrastructures, focusing on deployment, extension and retrofitting, and to implement the decision-support platform and embedded tools in selected cities, for local utilities and city administrations, focusing on thermal and electrical networks linked to low-carbon resources. To fulfil the projects, 3D city visualization methods are employed to illustrate the effects of the simulation and to communicate with the social participates related to the energy development planning.

The rest of paper is structured as follows: Section 2 summarized the related work. Section 3 proposed the overall framework and explained its key aspects. The demonstration results of the implementation are given in Section 4. Finally Section 5 concludes the whole paper.

2 Related work

2.1 Energy Simulation and CityGML

Energy simulation has been studied for a long time especially along the development of computer and Information technologies. Hundreds of building/city energy programs have been developed in past half century. Some of the representatives are Building Loads Analysis and System Thermodynamics (BLAST), BSim, DOE-2.1E, EnergyPlus,

and TRNSYS. Crawley et al. (2008) analysed and compared twenty energy simulation programs that are important in the field and widely used. It is indicated that there is not a signal one tool can deal with all aspects of building energy simulation, while users should considering a suite of tools for different application situation. Therefore, it is necessary to standardize the input and output so that they can be shared by different building/city energy simulation programs and users.

The input/output of energy simulation is city or building, for which many standards have been established such as Building Information Model (BIM) and CityGML. Kim et al (2015) have employed BIM for building thermal energy simulation. For BIM model, two commonly adopted open standards are IFC (Industry Foundation Classes) and gbXML (green building XML). They can both be used to extract inputs for energy simulation (Ham and Fard 2015, Kim et al. 2016). While Choi and Park (2016) pointed out the experience of exports is essential to apply BIM data for energy simulation. Meanwhile, the BIM model mainly concerned about single building, while it is necessary to analysis the energy consumption in a higher level such as city or urban and consider more factors like economy and relationship with other city objects that contain both energy producer and consumer. CityGML as one of the OGC standard for city object description has been extended for energy simulation (Coccolo et al 2015, Nouvel et al. 2015) and city utility network (Becker et al. 2013). Besides, CityGML covers many energy related city objects such as water, vegetation, transportation and so on. These information is essential for comprehensive energy simulation in city level (Bruse et al. 2015).

2.2   Non-photorealistic 3D visualization

3D city models are widely applied in many applications such as urban planning, municipal administration and so on (Biljecki et. al. 2015). And the large pro-portion of the existing visualization methods are mainly focus on photorealistic ones. However, to deliver city energy simulation results, non-photorealistic visualization method is required to illustrate the in-visible data or attributes about the city. Non-photorealistic visualization has been applied in 2D thematic map. Agrawala et al (2000, 2001) proposed a road network generation system that can convert the road map into hand draw style for simplicity and clarity. Li et al (2014) implemented an efficient road guide based on non-photorealistic landmarks. Moser et al. (2009) drawn the walking map using object transformation and screen relocation. The non-photorealistic visualization is also import for 3D city models (Döllner and Buchholz 2005).

Web based 3D visualization is become increasingly powerful along with the development of HTML5 and browser. Based on WebGL, current mainstream web browsers such as Chrome, IE, Firefox and Safari can all render the 3D scene directly. To further facility the web 3D visualization, frameworks such as Threejs, X3DOM, and Cesium are developed to provide an javascript based APIs for user to easily create and modify 3D scenes without knowing the underside rendering details. Wendel et al. (2016) used Threejs to visualize energy Modelling Results. Sturm et al. (2013) developed a web-based visualization of energy with X3DOM.

Wang et al. (2017) proposed a climate visualization system with Cesium. Compared with Threejs and X3DOM, Cesium supports the geospatial naturally. It can integrate different maps, satellite images and geo-services such as WMTS and WMF. Therefore, it is suitable for city level energy simulation results visualization. Even though, the capacity of web browsers has increased a lot, it is still necessary to simplify the 3D city models for better interactive visualization, which requires 3D city model generalization.

To generate the 3D non-photorealistic city models, visual variables should be studied. Visual variable is proposed by Bertin (1967, 1983) in cartography that contains size, shape, orientation, color, density and brightness. For 3D visual variables, Kraak (1994) added transparency and texture. Haeberling (2004) included location, focus area and object action. Therefore, to generate a non-photorealistic visualization for 3D city models we can map the invisible city data into the related visual variables. Meanwhile generalization is required to improve the visualization efficiency especially for the mobile applications which have become more and more common for users.

3   Methodology

3.1   Overall Framework

The system framework is illustrated in Figure 1. The 3D city models is integrated with energy information, city utility network infrastructure and other economy/society data such as electrovalency, environment policy and etc. These datasets are processed by input wrapper to CityGML format. If the metadata is already defined in CityGML such as building geometry or road network, it will directly be converted to the corresponding CityGML objects. Otherwise, the ADE or generic object/attributes will be used. Then, the energy simulator will read the city information from CityGML database and generate the formatted input files for simulation tools using output wrapper. Next, simulation results are saved into CityGML database through the input wrapper.

In visualization step, the original 3D city models, including geometry and attribute data, are first generalized into multiple Level of Details of different visual variables. Then the non-photorealistic visualization will be implemented based on combination of visual variables in suitable LoDs according to the requirements of users such as distance, orientation, and interested targets.

Figure 1: Framework of non-photorealistic visualization.
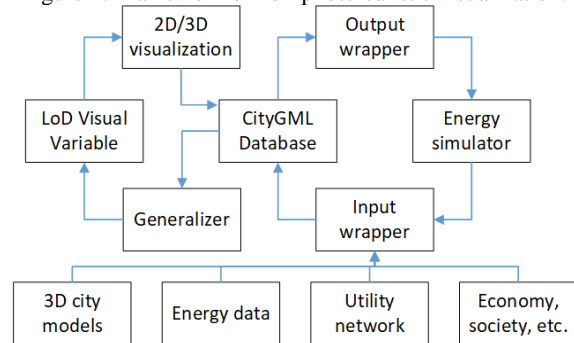
3.2   CityGML based energy data integration

City basic information. In fact, CityGML itself already contains rich geometric and semantic information that can be used in energy simulation, for example, building function, year of construction and other attributes. Meanwhile, CityGML can be extended by ADE and generic objects/attributes. For energy simulation, Energy ADE and utility ADE are proposed and they have potential to become the core part of CityGML. Therefore, in this paper, we first list the input parameters of energy simulation software/tools. Then for each parameter, its correspondent is checked in the CityGML metadata and ADEs. An ontology graph of citygml attributes and energy simulation parameter is structured to perform the matching. Finally, if one parameter is not defined in CityGML and ADEs, it will be saved as generic attributes or objects in CityGML. The parameter matching ontology graph also contains the generic information, and it will be used in the simulation parameter generation.

Simulation parameter generation. Even though, extended CityGML dataset could contain all the required information for energy simulation, it is still need to generate the input file according to the different analysis tools' definition. Here, the ontology matching graph between energy information and CityGML objects can be reused for input generation. Based on CityGML, we can combine a data extraction function with a formatted file generator to create a output wrapper for a certain energy simulator. Although, there are quite many simulators, the user often just use one or two of them. Therefore, a parameter generator can be predefined for a simulator or even become a part of the simulator, which will speed up the data preparation. In our experimentation, we develop python based and FME based parameter generator for the energy simulation tools Energyplus and TRNSYS. The new published CityGML energy ADE has covered most attributes required by the mainstream simulation. However, some local defined attributes is still needed for the self-defined simulation scenario.

Simulation results integration. The energy simulation tool exports different types of results, for example the electricity consumption, indoor temperature, airflow information and etc. Meanwhile, the analysis is usually generated not for entire building or area but for part of building (plane or zone). Also energy simulations contain temporal information such as period or timestamp. How to integrate the simulation outputs into CityGML and compare/combine results from different tools is a challenge task. In this paper, we predefined an input wrapper to deal with the output files from certain simulation tools. The information extracted from outputs is then saved as ADE or generic attributes to the simulated city objects. For example, if a building is analyzed for its CO_2 emission, the results of volume of CO_2 generated by the building will be saved as a generic attributes of the building. Considering the diversity of energy simulation, it is difficult to predefine all possible outputs. While we utilize the time series of CityGML Energy ADE to describe the type of simulation output results. In the visualization step, the time series are mainly analyzed since the static value can be considered as a special case of time series when the value is constant.

3.3   Generalization and Non-photorealistic Visualization

First, the visual variables of 3D city models are defined. Then the target data for non-photorealistic visualization is mapped with the predefined candidate visual variable set. For example the electricity consumption volume can be mapped into color or the size of a building depend on the application requirements. Next multiple datasets can be represented with multiple visual variables and integrated together for visualization. The generalization will be performed in each visualization such as geometry, texture or topology. Finally a multiple level of visual variables (LoV) structure will be created for dynamic visualization.

Figure 2 Non-photorealistic visualization framework.
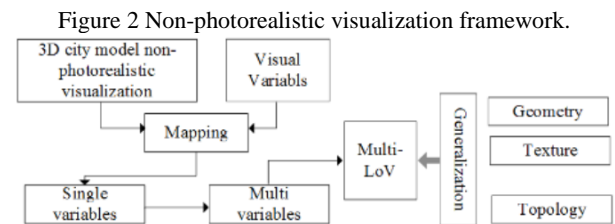
Visual variable mapping

Based on the existing researches and implementation technologies, visual variables for 3D city models are mainly including types as follows.

1. Geometry. The geometry visual variables include attributes such as shape (point, line, surface, and volume), location, size, scale

2. Texture. The texture visual variables are color, gray value, material, grain, transparency, resolution

3. Topology. The topology visual variables are mainly focus on the distribution of the object groups such as orientation, pattern, and arrangement

4. Environment. The environment visual variables are related with the 3D visualization settings for example 3D projection, Lighting, shading, shadowing, background, field of view, view point and view angle.

The visual variables will be adjust from devices or rendering technologies and new variable will be added and unsupported will be removed. To map the data for visualization with the right visual variable requires ex-perience and result tests. Usually two steps are required visual variable selection and quantity mapping. First, the visual variables should be parameterized and normalized. Then visual variables can be selected and mapped to the target data value for visualization. The generalization of visual variables is trying to simplify and reduce the volume the parameters to represent the variable.

Non-photorealistic generalization

Geometry simplification.

The tradition geometry representation is based on point set. Therefore, each object in 3D city models are unique, which increases the data volume and operation complexity. For non-photorealistic Constructive solid geometry (CSG) has better representation efficiency. To generalize the geometry visual variables, CSG of the 3D city models should be first generated

and parameterized by type, scale and orientation. Then for each type, multiple prototypes in different Level of Details can be stored for different request.

Texture generalization.

For texture related visual variables, one main method is to save texture images in multi-resolution. Along with the development of volume rendering, the volume pixel or voxel is widely applied in 3D city visualization, and it should be also compress into multi-resolution such as octree and so on.

Topology generalization.

We can generalize the topology of 3D city objects by detecting their distribution such as linear, grid and other patterns, then recreate the distribution with parameters such as type, interval, density, scale and orientation.

The generalization on each visual variables is determined by application requirements. For example, the energy consumption visualization may require more texture details than geometry information. Then based on the proposed framework, we can perform the generalization in each visual variables in different level to gain the satisfied results while removing the unnecessary information.

4 Experimental results

For the application of energy analysis, the power grid, heating/cooling system and gas pipeline are mainly taken into consideration. However in the photorealistic visualization, these facilities are usually unseen. Therefore the non-photorealistic visualization is required in this situation. Also the other related city objects such as building, road, water body and so on should be visualized in non-photorealistic way.

Figure 3: Implementation framework of energy simulation.
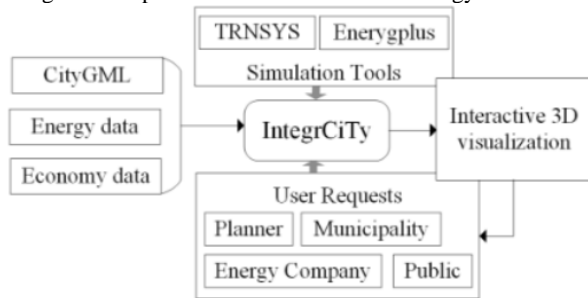
In the experiment implementation, we identify the visual variables for both city and energy objects. Geometry, texture and topology are mainly considered as the target visual variables. We create the multiple representations for each visual variables and integrate them from different LoDs into a complete visualization sensorial. Meanwhile, the visual variables will also be used for simulation results visualization. We create a HTML5 based 3D rendering framework using three.js which is an open source 3D engine for web applications. The results indicate that web based visualization for 3D energy simulation is efficient than the tradition programs since it reduces the development work loads and

supports the multiply clients like PC, mobile devices and VR equipment. Figure 4 shows a demo result of non-photorealistic visualization of energy simulation.

Figure 4: Non-photorealistic visualization results.
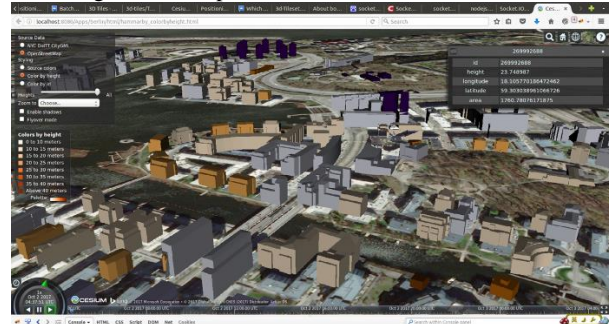
5 Conclusions

In this paper, we developed a GUI based on Cesium framework to visualize the energy simulation results. To improve the visualization performance, the 3D city models are generalized for non-photorealistic visualization that is an essential technology for smart city applications to illustrate different types of information. We propose a strategy to map the data for visualization to the visual variables of 3D city models such as geometry, texture, topology and environment. Generalization on each visual variables are applied to speed up the data transmission and rendering. A demo project on energy simulation for sustainable city analysis is developed to show the effectiveness of the proposed method. The experimental results show that non-photorealistic generalization is essential for online 3D city related applications and can improve the system performance while supplying the required visualization results.

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