URBAN ENERGY SIMULATION OF THE EPFL CAMPUS IN FRIBOURG USING A NEW PARADIGM: THE CITYGML APPLICATION DOMAIN EXTENSION ENERGY

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ABSTRACT

Rapid urbanisation and the increasing world population call for a new approach in urban design, favouring energy efficiency and sustainability of the built environment. When focusing on City Energy Modelling, unlike Building Energy Modelling, each urban simulation engine generally has its own tailor-made data-model: municipalities and other urban information data administrators use their own data base structure to collect and manage urban information data, without the possibility to store and share urban models. To address this issue, since May 2014, an international consortium of urban energy simulation developers and users is establishing an Urban Energy Information standard, as Application Domain Extension (ADE) of the CityGML urban information model. This paper presents a methodology to establish a gateway between one of the urban simulation tools CitySim and the CityGML Energy ADE data format. The future EPFL campus in Fribourg is presented as case study, demonstrating the storage possibility of the CityGML Energy ADE of geometrical properties and annual heating and cooling demands for each building. The connection between CitySim and CityGML Energy ADE represents an innovative approach to urban energy analysis: a city model can be simulated, stored and exchanged between the two formats creating a common database of knowledge, in which researchers and municipalities could share their results.

Keywords: CityGML, Urban Energy Simulation, urban data model

INTRODUCTION

Due to a rapid urbanization throughout the planet, planners and decision makers from municipalities are facing important challenges in controlling the growth of the number of shelters and their associated energy consumption. Furthermore, the current densification of city centres demands inevitable planning choices that need to be addressed from the city scale point of view in order to mitigate traffic and building energy consumption but also to increase the use of renewable energy sources. To address these urban scale elements, specific algorithms and software solutions have recently been developed by international research centres and private sector actors.

When focusing on City Energy Modelling, unlike Building Energy Modelling where few well-established building information model standards exist (IFC, gbXML, etc.) and serve as exchange support between different tools and experts, each urban simulation engine generally has its own tailor-made data-model. The situation gets even more complicated as municipalities and other urban information data administrators use their own data base structure to collect and manage urban information data. This leads to multiple import and export features for the different tools that may complicate the life of practitioners and feel like an everlasting starting over.

To address this issue, an international consortium of urban energy simulation developers and users (11 European organisations[1] representing 5 urban energy platform developments[2]) has since May 2014 been working on an Urban Energy Information standard, as Application Domain Extension (ADE) of the CityGML urban information model. CityGML is a XML-based open data model for the storage and exchange of virtual 3D city models, issued by the Open Geospatial Consortium (OGC) [1]. CityGML is organised around a CityGML core model, prolonged by Application Domain Extensions (ADE) for different purposes such as: geometry, construction, occupancy and energy systems. With the Energy ADE under development, the set of ADE will allow adding energy related information to existing CityGML models. The CityGML core is already well established for the modelling of whole agglomerations (Berlin, Lyon) [2] [3], regions and countries (Germany) [4]; it offers possibilities for numerous and varied spatial analyses at city scale, such as noise mapping, urban wind flow studies, photovoltaic potential or flood risk analysis. A considerable asset of CityGML is its flexible object modelling at different Levels of Details [5], enabling the virtual city model to adapt to local building parameter availability and application requirements.

This paper starts with a brief introduction of the specificities of the CityGML Energy ADE standard and presents the first simulation results based on CitySim simulation. CitySim is an urban energy modelling able to quantify heating and cooling demand from a single building to the urban scale with simplified input physical and geometrical data [6]. The aim of this study is to use as a first case-study the project of the EPFL campus in Fribourg to be completely described (geometrically and physically) using the CityGML Energy ADE with a level of detail allowing for hourly dynamic simulations. The first results are visualized with FZKViewer [8], a free program able to read and display geometrical 3D CityGML data. Further results showing the thermal behaviour of the campus today and in future climatic scenarios, according to Institute panels of Climate Change (IPCC) - scenarios A1B, A2 and B1 [7], are stored using the CityGML Energy ADE. The paper concludes with an analysis of the future possibilities offered by the new data model.

METHODOLOGY

The methodology aims to show the gateway between CitySim and CityGML data models. It starts by explaining the paradigms behind the CitySim data model, and follows by detailing those of CityGML Energy ADE. It ends by defining the case-study on which we will shift from the CitySim to the CityGML data model to demonstrate the exchange of information concerning geometrical properties of buildings and their annual energy demand.

CitySim data model

The CitySim data model is based on the XML (eXtensible Markup Language) format and composed of different modules defining each a building in the scene:

- Building thermal zone, which contains the information about volume, set-point temperatures for heating/cooling, infiltration rate and thermal bridges, but also:
    - Occupation (number of occupants, and their profile during the day)

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[2] CitySim, SimStadt, Energy Atlas, Modelica library AixLib, Sunshine platform.

  - Description of the Walls (geometrical and physical, together with the characteristics of the windows and photovoltaic systems)
  - Description of the Roofs (same parameters)
  - Description of the Floors (same parameters)
- Energy system for heating and cooling purposes.

The structure is tree-based with objects included in other objects such as Walls inside a Thermal Zone inside a Building.

CityGML with Energy ADE data model

CityGML with Energy ADE is structured by the following four interrelated modules, which are linked to the 3D information in the CityGML core through references:

- Building, Zones and Boundaries: contains information concerning building geometry, thermal zones, opening and schedules.
- Construction and Layers: defines physical characteristics of the envelope, such as materials, and their physical and optical properties (emittance, absorptance, transmittance, and reflectance).
- Occupancy Module: describes the usage of the building, the presence of occupants, and the consequent usage of facilities and appliances.
- Energy System Module: describes the energy demand supplied by different energy systems (conversion, distribution and storage).

The four modules are completely independent of each other, may also not be present and are linked together through references.

The gateway between CitySim and CityGML Energy ADE data model

According to previous analysis, the CitySim and CityGML data model have common data organized in different structures. The structure of the CitySim data model is tree-based, where a district contains buildings, and each building contains thermal zones, which contain further information about the building such as physical and geometrical characteristics. On the other hand, the structure of the CityGML data format is organized in independent modules which may or may not be present for each building. Figure 1 summarizes the idealized structure of CitySim (a) and CityGML Energy ADE (b). In CitySim the building tag contains all information about the building; on the other hand with the CityGML Energy ADE each module is linked with the CityGML core and some modules are interconnected between them: Building, Zones and Boundaries are linked with Occupancy and Energy System modules, and the latter is connected with Construction and Layer.

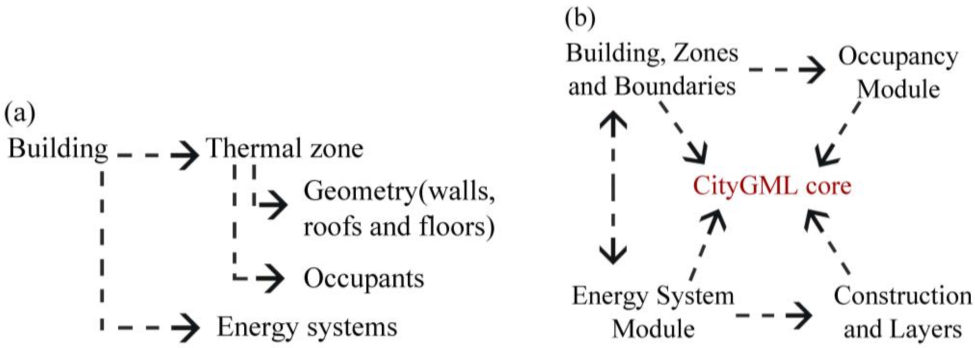

Figure 1 Idealized data structure of CitySim (a), and CityGML Energy ADE (b)

An adequacy between the two data models can be defined: both 3D geometrical and physical data from the CitySim data model can be transferred to the CityGML data model. The same process can be established for the simulations results: urban models simulated with the CitySim software can be saved using the CityGML Energy ADE including the annual heating and cooling demand of each building.

Case study: the EPFL campus in Fribourg

The EPFL campus in Fribourg will be an outstanding centre of research in technology, construction and sustainable architecture; this centre will be set up in collaboration with the School of Engineering and Architecture HEIA-FR and the University of Fribourg. The scientific pole, called BlueFACTORY, will host academic and private partners, promoting public-private partnerships. The site is under construction and an international design competition drew the masterplan design [9] that is composed of nine new buildings, among which the Smart Living Lab, a smart building able to combine sustainability with human wellbeing.

The numerical model of the campus was established with the software CitySim from geometrical DXF data and completed with physical attributes corresponding to Minergie-P standards. The envelope is designed as a double concrete wall with a central EPS insulation layer and a U-value equal to 0.1 ($W \cdot m^{-2} \cdot K^{-1}$); the windows are made of triple glazing with argon covering 0.5 of the façade, their U-value is equal to 0.7 ($W \cdot m^{-2} \cdot K^{-1}$) and g-value equal to 0.7. The total area of the campus is about 77.000 m^2 according to original 3D geometry [10]. The buildings are simulated without occupants and electrical devices, under current and future climatic scenarios (IPCC 2100 A1B, A2 and B1).

RESULTS AND DISCUSSION

Using the previously described methodology, we present in what follows the abilities of the CitySim software to export the geometrical information to the CityGML data format, and to further export the annual simulation results for heating and cooling demands using the CityGML Energy ADE.

Geometrical information

The model of the EPFL campus in Fribourg presented in Figure 2 is read and displayed by the FZKViewer. The geometrical data exported maintain a distinction between walls, roofs and floors.

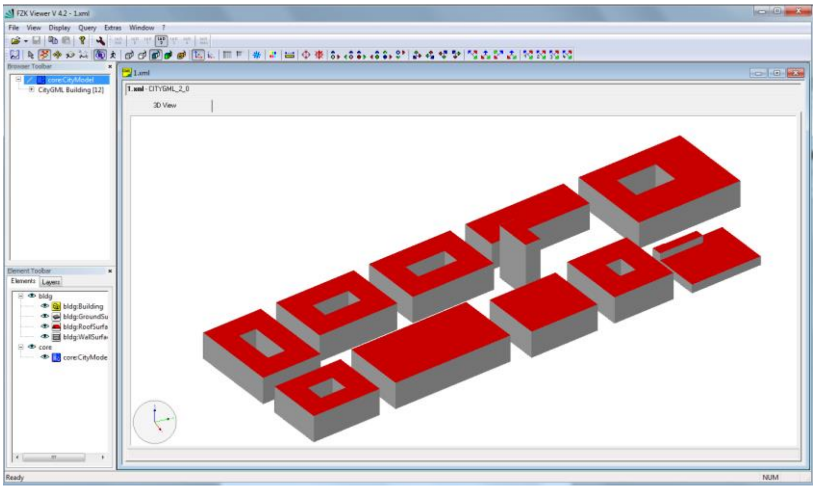

Figure 2 EPFL campus in Fribourg exported in GML format

Annual energy demand for heating and cooling

The results obtained with CitySim are stored using the CityGML Energy ADE. According to last year's averaged weather data, the campus would consume 1300 GWh for heating and 590 GWh for cooling (to maintain a maximum internal temperature of 26°C during summer). In future climatic scenarios the heating demand would decrease by 6% (scenario B1) to 17% (scenario A2) and the cooling demand would increase by 35% (scenario B1) to 140% (scenario A2). In scenario A2 the averaged energy demand for cooling will be 18 kWh/m^2 slightly higher than the heating demand which is equal to 14 kWh/m^2. Figure 3 shows the annual heating demand of the site for the current climate scenario (expressed in kWh/m^3 per each building) using a 3D representation and a colour scale, and Figure 4 shows an extract of the corresponding CityGML ADE Energy XML file. The energy demand for heating (<energy:id> SpaceHeating_1 </energy:id>) and cooling (<energy:id> SpaceCooling_1 </energy:id>) is defined for each building and expressed in kWh per year, under the tag: <energy:values>156412.8</energy:values>. The tag <gml:TimePeriod> represents the period of simulated results, in this case annual.

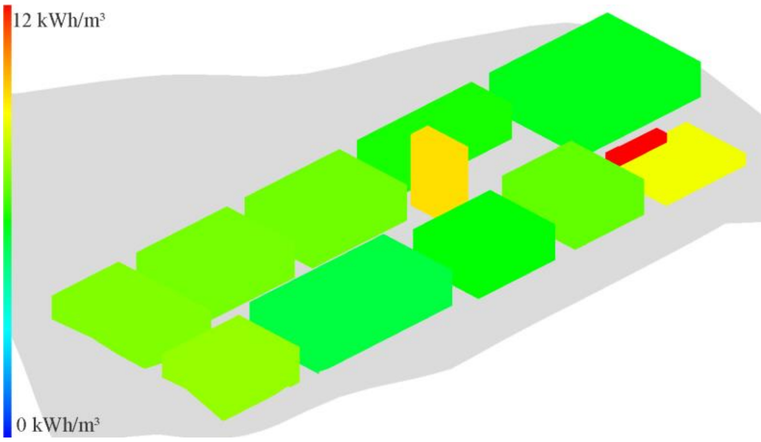

Figure 3 Heating demand of the EPFL campus in Fribourg, today scenario. 3D representation with colour scale

```
<energy:energyAmount>
    <energy:RegularTimeSeries>
        <energy:id>SpaceHeating_1</energy:id>
        <energy:temporalExtent>
            <gml:TimePeriod>
                <gml:beginPosition>01.01.2014</gml:beginPosition>
                <gml:endPosition>31.12.2014</gml:endPosition>
            </gml:TimePeriod>
        </energy:temporalExtent>
        <energy:variableProperties>
            <energy:TimeValuesProperties>
                <energy:acquisitionMethod>Simulations</energy:acquisitionMethod>
                <energy:interpolationType>Continuous</energy:interpolationType>
                <energy:qualityDescription>None</energy:qualityDescription>
                <energy:source>On-site sensor measurements</energy:source>
                <energy:uom uom="kWh"/>
                <energy:variableLabel>Heating demand</energy:variableLabel>
            </energy:TimeValuesProperties>
        </energy:variableProperties>
        <energy:timeInterval unit="year">1</energy:timeInterval>
        <energy:values>
            156412.8
        </energy:values>
    </energy:RegularTimeSeries>
</energy:energyAmount>
```

Figure 4 Heating demand of the EPFL campus in Fribourg, today scenario. Extract of the CityGML ADE XML file

These results show a new paradigm in data format, which can be simulated with the software CitySim and exported in the CityGML ADE data format: this gateway allows the creation of a common database, where data (geometrically and energetic results) are readable by different viewer.

CONCLUSION

Several computer tools quantify the energy demand and thermal behaviour of buildings, from the urban to the edifice scale, but none of them is actually able to convert and exchange information between them different at the urban scale. For this reason, a new paradigm called the CityGML Energy ADE is under development. This paper presents a methodology to establish a gateway between one of the urban simulation tools CitySim and the CityGML Energy ADE data format. The future EPFL campus in Fribourg is presented as case study, demonstrating the storage possibility of the CityGML Energy ADE of geometrical properties and annual heating and cooling demands for each building. The connection between CitySim and CityGML Energy ADE represents an innovative approach for the urban energy analysis: city model can be simulated, stored and exchanged between both format creating a common database of knowledge, in which researchers and municipalities could share their results. Future development of this research topic will focus on displaying results obtained through different software in graphical user interfaces.

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