GENESIS OF THE CITYGML ENERGY ADE

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ABSTRACT

The current climate and environmental policy efforts require comprehensive planning regarding the upgrade of the energy supply and infrastructures in cities. Planning comprises e.g. the determination of locations for new power generating facilities like photovoltaic, geothermal and decentralized combined heat and power stations, the widespread introduction of e-mobility solutions and hence the grid development as well as large-scale energetic building refurbishments. A holistic approach integrating extensive complex information is essential for the strategic planning of the different measures. In order to establish interoperability and data exchange between the different planners, stakeholders, and tools, an open information standard is required.

To answer this need, an international group of urban energy simulation developers, geo-information scientists and users from 11 European organizations is developing an Application Domain Extension (ADE) Energy for the OGC open standard CityGML. This paper presents the collaborative development of this new open urban information model, including its genesis, objectives, structure and next planned steps.

INTRODUCTION

Urban Energy Modelling and Simulation has seen a substantial development during the last decade, boosted by two factors; the shift of the energy transition paradigm at the city scale level, and the increasingly high computational performances reached by multi-core microprocessors and Graphic Processing Units. In the past few years, international research centres and private sector actors have developed specific algorithms and software solutions (e.g. CitySim, UMI), which provides new digital methods for energy planning and decision support. Decision makers, in municipalities, housing authorities, energy supply companies and other stakeholders are just getting used to the enormous potential of them.

However, contrary to Building Energy Modelling, where a number of well-established Building Information Model (BIM) standards (IFC, gbXML) serves as exchange support between different tools and expert fields, allowing for high interoperability possibilities, no comprehensively applicable model standard exists until now for Urban Energy Modelling. Therefore, developers of new urban energy tools have created their own tailor-made data-models, while municipalities and other urban information data administrators have their own database structure to collect and manage urban information. As such, these models exist without interoperability possibilities, necessitating that each new attempt at developing a comprehensive Urban Energy Model begin from the ground up.

An open Urban Information Model standard namely exists to encode, store and exchange virtual 3D city models and landscape models: CityGML [1], which is developed by the Open

Geospatial Consortium (OGC). This XML-based data model defines classes and relations for the most relevant 3D topographic objects in cities (e.g. buildings, transportation infrastructures, city furniture, water bodies) regarding their geometry, topology, semantics, and appearance. In particular, the representation of buildings includes WallSurface, GroundSurface, and RoofSurface as well as for the description of the roof shape, usage type, number of storeys, construction year, and building height. A considerable asset of CityGML is its flexible object modelling in different Levels of Details, enabling the virtual city model to adapt to local building parameter availability and application requirements (see Figure 1). However, since CityGML is an application independent information model, it does not include specific energy-related elements naturally.

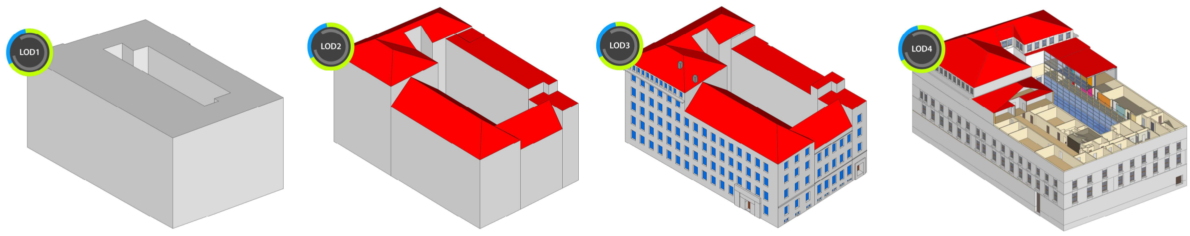

Figure 1 Building 2 of HFT Stuttgart, represented in the four Levels of Detail (LoD) of the OGC standard CityGML (source: HFT Stuttgart)

With the CityGML concept of Application Domain Extensions (ADE), it is possible to incorporate domain-specific entities which are not pre-defined in CityGML standard. Concretely, an ADE is represented by an XML-Schema using a specific namespace (energy in our case), interfacing with the CityGML base schema. The ADE concept supports two different methods for extending the base standard, detailed in the OGC "Best Practices Document" [2]:

- Existing CityGML classes can be extended by additional attributes or relations ("ADE-attributes"). ADE-attributes substitute the CityGML generic attributes and additionally support relations to geometry objects, CityGML or ADE feature classes, and the usage of Enumerations or Codelists.
- In the ADE schema, new classes ("ADE-classes") can be defined, which optionally can be derived from existing CityGML classes using the generalisation concept. In consequence, an ADE-class inherits all attributes and relations of the base class.

Due to the rich information model, its extensibility, and the rapidly increasing data availability all over the world, the combination CityGML + ADEs is a suitable information model for a common engineering data backbone for urban energy, environmental, and mobility planning.

PRELIMINARY WORK

In the past few years, the University of Applied Sciences Stuttgart (HFT) and the Technische Universität Munich (TUM) have developed new urban energy simulation platforms, SimStadt (HFT) and Energy Atlas (TUM), based on the CityGML data model. While their input requirements for the calculation of the building heating demands were going far beyond the available data structure of CityGML, they developed in parallel two different drafts of Energy Application Domain Extensions (ADE).

In order to exchange the models and compare the energy simulation results, HFT and TUM started working together on the harmonization of the ADE models into a unique Energy ADE.

Since that, several international urban energy simulation developers and users have joined this initiative. In May 2014, an international group of experts from 11 European organisations from Germany, France, Italy and Switzerland met to plan together the development of a common Energy ADE for the CityGML urban information model. They were representing six urban energy simulation platform developments: CitySim [3], SimStadt [4], EnergieAtlas [5], Modelica library AixLib [6], Sunshine platform [7] and the Curtis platform [8]. This collaborative work led to a first release of the Energy ADE in February 2015, which this paper introduces.

OBJECTIVES

The objective of this Energy ADE is to store and manage data required for the calculation of the building energy flows and its main results in the CityGML-based virtual 3D city model. The physical boundary of this new data model is the building envelope, including the systems installed on it (e.g. solar panel, shading devices). Small-scale centralized energy systems may also be modelled in this Energy ADE. However, urban centralized energy infrastructures, like district heating system or gas network, are not in the scope of this development, since they are already represented by the CityGML Utility Network ADE [9]. The Energy ADE allows for interfacing with the utility networks through substation node objects.

Following the philosophy of CityGML, this Energy ADE aims to be flexible, in terms of compatibility with different data qualities, levels of details and urban energy model complexities (from monthly energy balance, to sub-hourly dynamic simulation of software like CitySim or EnergyPlus). It aims to be integrated as far as possible within the existing CityGML data model, avoiding the creation of a parallel data structure that would be tailor-made for specific calculation methods. Moreover, this Energy ADE considers the existing international building and energy data specifications, like the INSPIRE Directive of the European Parliament, as well as the recent US Building Energy Data Exchange Specification (BEDES), and integrates their relevant energy-related attributes.

An important issue is also to track and manage the diversity of data sources and data qualities, which highly affects the reliability and precision of the energy calculation results. For this purpose, a concept of metadata is currently under development within the Energy ADE working group. As it seems to be a general concern for many present CityGML developments, we foresee a coordinated work with other CityGML developers in this field.

A MODULAR STRUCTURE

The Energy ADE is presently structured in 3 modules and a core model:

- Construction and materials
- Building Occupancy
- Energy and Systems

This structure enables to potentially reuse and extend some of its modules in other domains and applications, with data exchanges and interoperability opportunities. For instance, socio-economic studies may make use of the Energy ADE module Occupancy, while the module Constructions and Materials could also be applied for acoustics or statics.

Energy ADE core

The Core of the Energy ADE contains the thermal building objects required for the building energy modelling. These thermal building objects are linked to CityGML building objects through the CityGML abstract classes *_AbstractBuilding*, *_BoundarySurface* and *_Opening.*

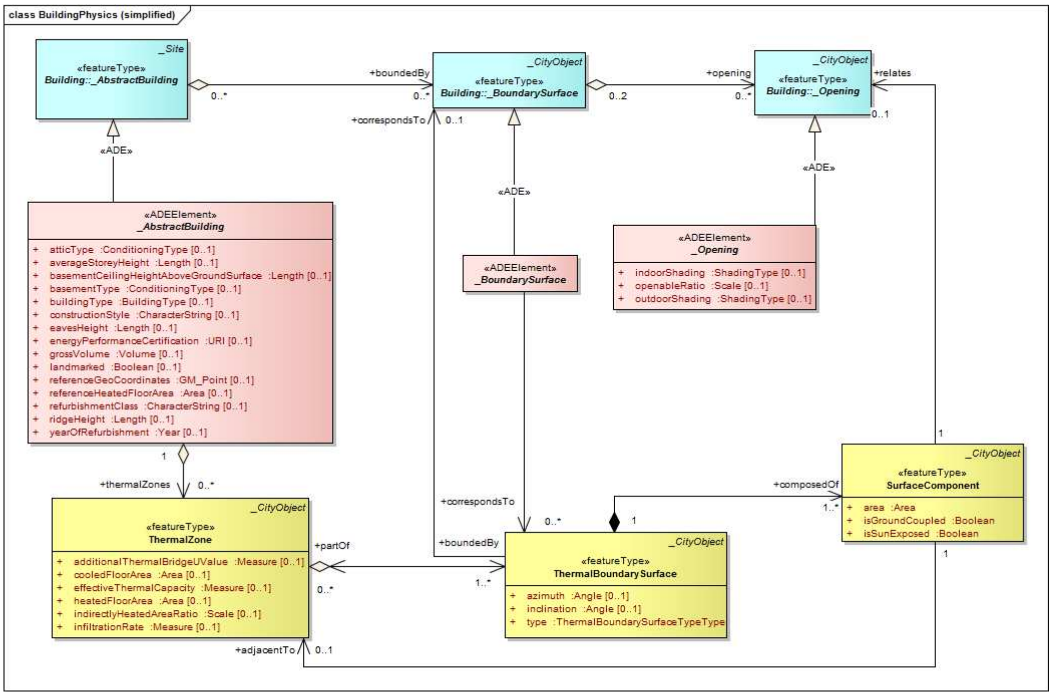

Figure 2 UML diagram extract of Building Energy ADE core

This schema is designed to be compatible with the four Levels of Detail (LoD) of CityGML while modelling faithfully the different thermal zones. A building may have one or more *ThermalZone* objects, which can be linked to a CityGML geometric object (e.g. *Building*, *BuildingPart*, and *Room* in the LoD4 case) or be pure semantic objects (e.g. storey for a CityGML Building whose LoD is lower than 4). Similarly, the *ThermalBoundarySurface* objects may correspond to a CityGML *_BoundarySurface* (e.g. roof, outer wall) or not (e.g. in case of an attic floor bounding the thermal zone for a CityGML Building LoD2-3).

The *_AbstractBuilding* extension contains energy-related attributes relevant for the building energy analysis, partly inspired by the INSPIRE data specification.

Construction and Materials

This Energy ADE module may be used and further extended for multi-field analysis (e.g. statistics and acoustics). It contains the physical characterization of building construction elements and can be flexibly associated with any CityGML *_CityObject* (in particular a *SurfaceComponent*, a *ThermalBoundarySurface* or a whole *Building*).

This module is based on a hierarchical structure *Construction*, *Layer*, *LayerComponent* and *Materials*, inspired by the gbXML format.

Flexibly designed, the data model is applicable for static energy balance purpose (which required the building contruction's U-Values and windows g-Values) as well as for more complex transient heat simulation. For this latter, the data model provides the material thermal characteristics of each construction layer. Thus, the level of detail of these parameters fits the granularity of urban energy models and the data availability.

Building Occupancy

This Energy ADE module may also be used and further extended for multi-field analysis (e.g. socio-economics, demographics and census data). It contains the characterization of the building usage, including HVAC operation set points, ownership and occupancy information as well as information about the owner and facilities. This module connects to all other elements of the Energy ADE *(_AbstractBuilding* and *ThermalZone*) through the class *UsageZone,* which defines a zone of a building with a usage type considered as homogeneous. One or several *UsageZone* may be associated to a *ThermalZone*, giving the flexibility to model mixed-use buildings with a mono-zone or multi-zone building model. *UsageZone* may have one or several Occupancy and Facilities objects. The object *Occupancy* represents a homogeneous group of occupants (the decision was made not to model single occupants for privacy reasons).

Temporal variables, such as occupancy rate or operation schedules (for heating, cooling, ventilation or any facilities), can be modelled with different levels of details, depending on the modelling purpose and the data availability: *ScheduleLoD0* corresponds to a constant average value. *ScheduleLoD1* distinguishes usage and idle values and set their daily switch time. *ScheduleLoD2* is a collection of typical daily schedules, while *ScheduleLoD3* corresponds to detailed time series.

Energy and systems

This Energy ADE module contains information concerning the energy forms (energy demand, supply and sources) and the energy systems (conversion, distribution and storage systems).

An *EnergyDemand*, which may be associated to any *CityObject* (in particular *Building*, *ThermalZone*, *UsageZone*, *BuildingUnit* etc.). This object represents the useful energy required to satisfy a given end use type such as heating, cooling, domestic hot water etc.. Other energy forms are *EnergySupply*, representing the part of the energy produced by the energy conversion systems, which is supplied to satisfy the energy demand, and *EnergySource*, corresponding to the final energy consumed by an energy conversion system.

All energy form objects are characterized by an *energyAmount*. It corresponds to a regular or irregular time series, containing variable properties such as *acquisitionMethod* (e.g. simulation, metering) or *interpolationType*. Therefore, both simulation results and metering data may be stored in the data model, for instance for a comparison purpose. Moreover, different time steps (sub-hourly to yearly, regular or not) corresponding to different building simulation methods and metering systems may be used.

The *EnergyConversionSystem* objects, which contains general parameters such as *nominalEfficiency* or *yearOfManufacture*, are specified by energy conversion technologies such as *Boiler*, *SolarThermalSystem* etc… These systems may have different operation modes for the needs of the different end uses, e.g. a reversible heat pump may supply during a year the space heating demand, the domestic hot water demand and the space cooling demand, representing three operation modes with different efficiencies, control strategies and operation time. The produced energy (power or thermal) is then supplied to the end users through energy distribution and energy storage systems.

CONCLUSION AND PERSPECTIVES

With the common objective of improving data exchange and tools operability in the urban energy modelling community, an international expert group of research institutes, standardisation organisations and GIS companies has extended the open city model standard CityGML with an Energy ADE. This new development is a long iterative process, which has just delivered its first results with this first XML Schema release 0.5.0.

During the second semester 2015, a test phase will allow confronting the Energy ADE schema with concrete real project and software integration issues. The numerous and diverse urban energy modelling and simulation tools used and developed by the different partners of this expert group will serve as test applications, in order to verify and optimize the Energy ADE flexible design. The present release is freely accessible on the SIG3D website: http://www.sig3d.org/citygml/2.0/energy/. New active participants are very welcome in this continuing development and test process.

ACKNOWLEDGMENT

We would like to thank all members of the Energy ADE development group who contributes voluntarily to the present development: University of Applied Sciences Stuttgart, Technische Universität Munich, Karlsruhe Institute of Technology, European Institute for Energy Research, RWTH Aachen University / E.ON Energy Research Center, HafenCityUniversität Hamburg, M.O.S.S Computer Grafik Systeme, Centre Scientifique et Technique du Batiment, Electricité de France, Sinergis and Ecole Polytechnique Fédérale de Lausanne. Thanks in particular to the Special Interest Group 3D (SIG3D) who provides the group with its infrastructure and an official framework to our work.

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