DEVELOPMENT OF THE CITYGML APPLICATION DOMAIN EXTENSION ENERGY FOR URBAN ENERGY SIMULATION

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ABSTRACT

No widely applicable open information model standard exists until now for large-scale Urban Energy Modelling. Although different data models have been developed for different urban energy tools, they do not offer possibilities of interoperability and exchange between the stakeholders, tools and expert fields.

To address this issue, an international group of urban energy simulation developers and users is developing since May 2014 an Application Domain Extension (ADE) Energy for the open urban information model CityGML.

This paper introduces the Energy ADE developed and tested by this international urban energy group. Goals, requirements and the modular structure of the CityGML extension are described in detail.

INTRODUCTION

Urban modelling of building energy is more than the simple addition of building energy models. With this change of scale, building interactions, microclimate phenomena, simultaneity effects and mutualisation of energy loads must be considered. A modelling simplification strategy is generally also required while dealing with districts with several hundreds or thousands of buildings. This enables to adapt to lower data availabilities (particularly for existing district), and keep simulation computational time acceptable and consistent with the global model precision.

During the last decade, Urban Energy Modelling has seen an exponential development, mainly 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. Recently, specific algorithms and software solutions (e.g. CitySim, UMI) have been developed by international research centres and private sector actors. Municipal decision makers, housing authorities, energy supply companies and other stakeholders are just getting used to the enormous potential of them.

However, contrary to Building Energy Modelling (BIM) where a number of well-established Building Information Model standards (IFC, gbXML) serve as exchange support between different tools and expert fields allowing for high interoperability possibilities, no widely applicable model standard exists until now for Urban Energy Modelling (Casper 2014).

An open Urban Information Model standard namely exists to encode, store and exchange virtual 3D city models and landscape models: CityGML (Gröger et al. 2012), which is developed by the Open Geospatial Consortium (OGC). 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. Unfortunately, it contains no energy-related objects and attributes presently.

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.

ADE DEVELOPMENT

For the requirements of their new urban energy simulation platforms SimStadt and EnergieAtlas, the University of Applied Sciences Stuttgart (HFT) and the Technische Universität Munich (TUM) extended CityGML with two independent Application Domain Extensions (ADE) Energy for the same original purpose: the thermal calculation of the building heating demand.

The CityGML concept of Application Domain Extensions (ADE) enables to specify extensions of the CityGML standard for specific fields and applications, since CityGML has not been designed to support a specific application area. Concretly, 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" (van den Brink et al. 2014):

- 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.

In order to exchange their models and compare the energy simulation results, HFT and TUM started working together on the harmonization of their data models into a single Energy ADE. Since, 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 the development of a common Energy ADE for the CityGML urban information model. They were representing six urban energy simulation platform developments: CitySim (Robinson et al.2011), SimStadt (Nouvel et al. 2015), EnergieAtlas (Kaden and Kolbe 2014), Modelica library AixLib (Lauster et al., 2014, available on github.com/RWTH-EBC/AixLib), Sunshine platform (Giovanni et a. 2014) and the Curtis platform (Blin et al. 2015).

This collaborative work led to a first release of the Energy ADE in February 2015, which this paper introduces.

SCOPE AND AIMS

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 (Becker et al., 2011). 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 structured modularly in order 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 (see Fig. 1). These thermal building objects are linked to the CityGML building objects through the CityGML abstract classes *_AbstractBuilding*, *_BoundarySurface* and *_Opening*.

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.

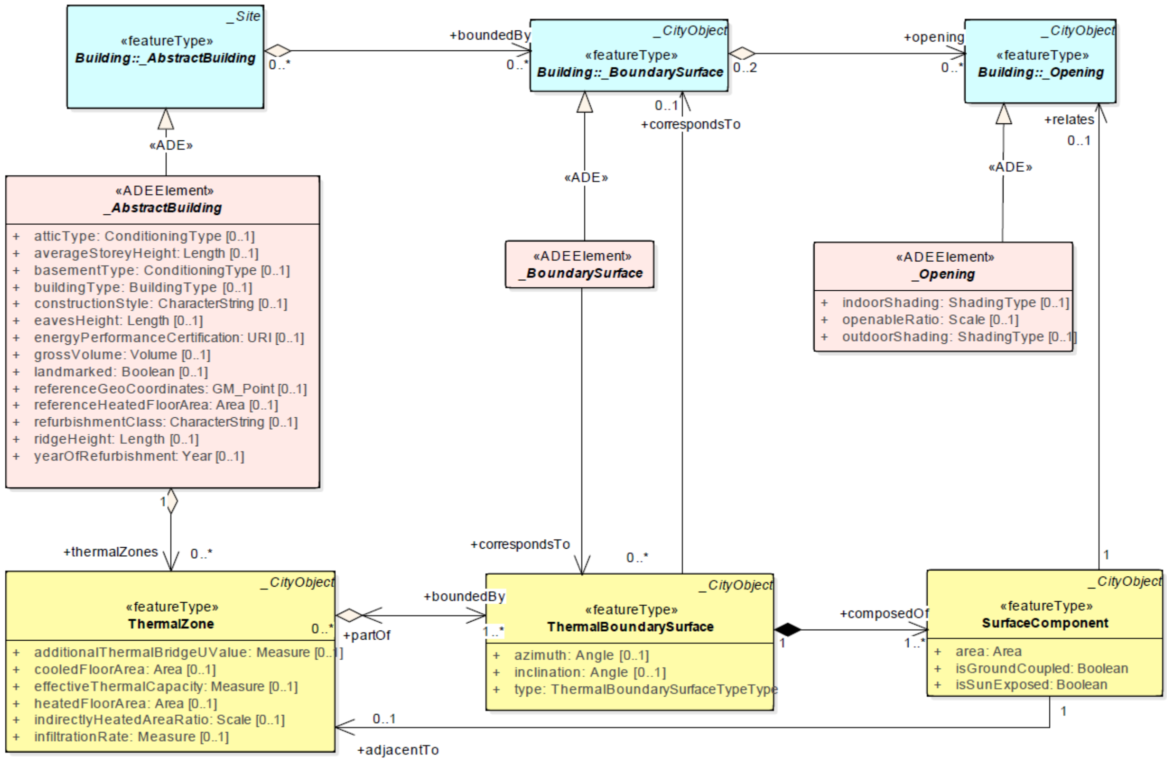

Figure 1 UML diagram extract of Building Energy ADE core

Constructions 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 facilities (see Fig. 2). This module connects to the rest of the Energy ADE (*_AbstractBuilding* and *ThermalZone*) through the class *UsageZone*, which defines a zone of 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.

The *BuildingUnit* object is a part of the *UsageZone*, which relates to a single occupant entity, such as a dwelling or a workplace. This object holds in particular the owner information data, which are for instance useful for energy refurbishment studies.
Both *BuildingUnit* and *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 (see Fig. 3), 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.

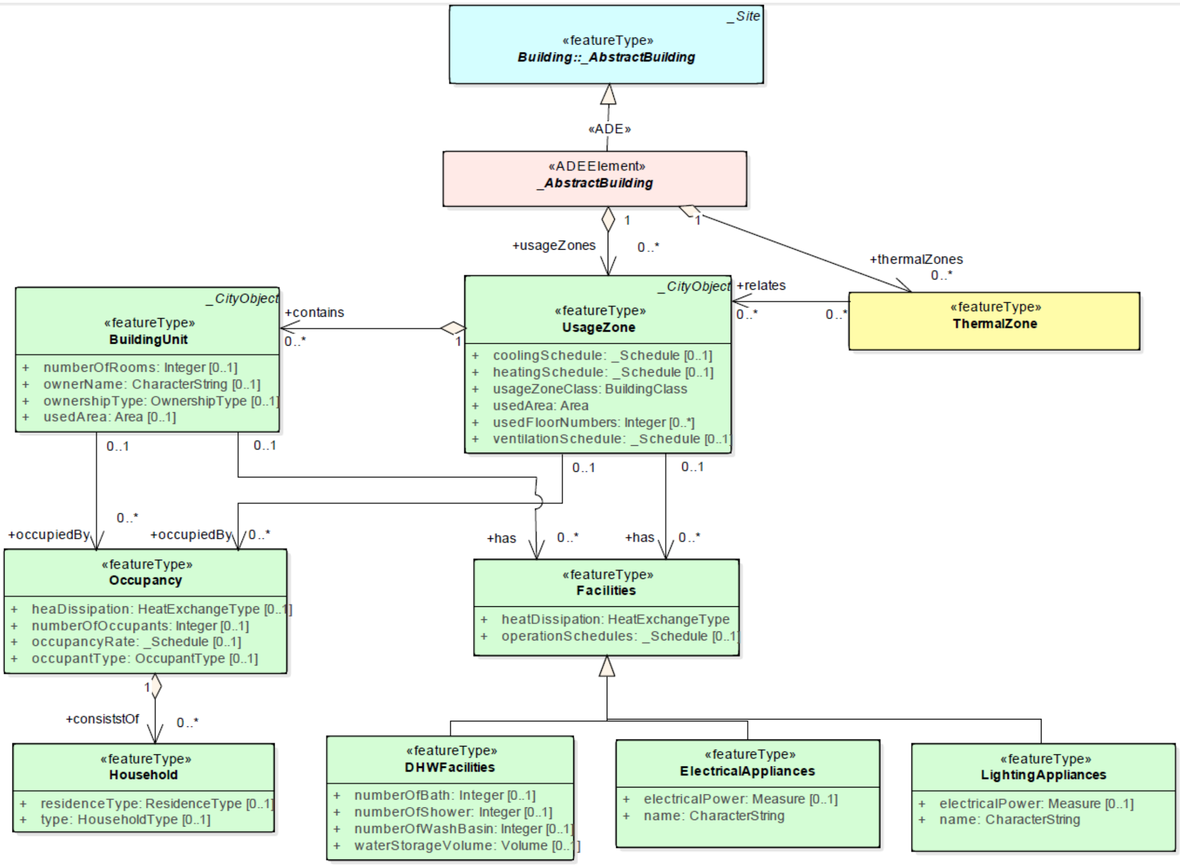

Figure 2 UML diagram extract of Occupancy Module

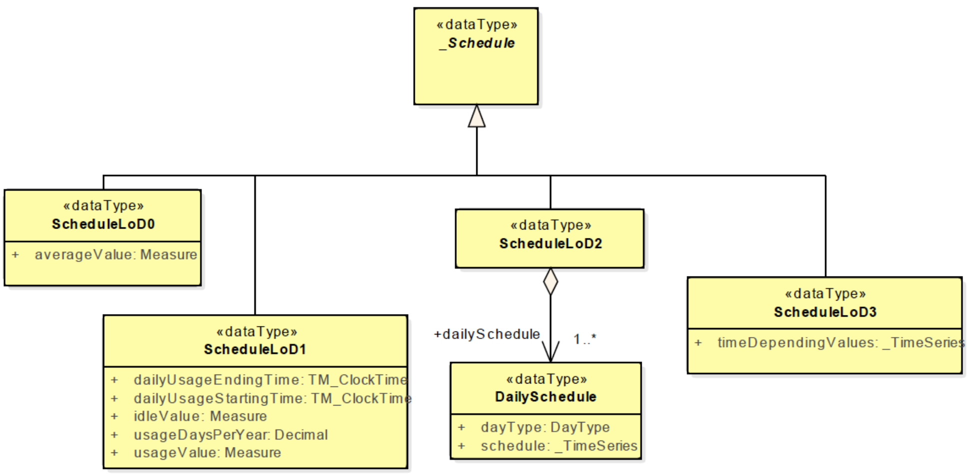

Figure 3 UML diagram extract of Schedule LoDs

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).

The *EnergyDemand*, which may be associated to any *CityObject* (in particular *Building*, *ThermalZone*, *UsageZone*, *BuildingUnit* etc.), realizes the connection with the rest of the Energy ADE. This object represents the useful energy required to satisfy a given end use type such as space heating, cooling, domestic hot water etc. Other energy forms present in the Energy ADE 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 contain 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.

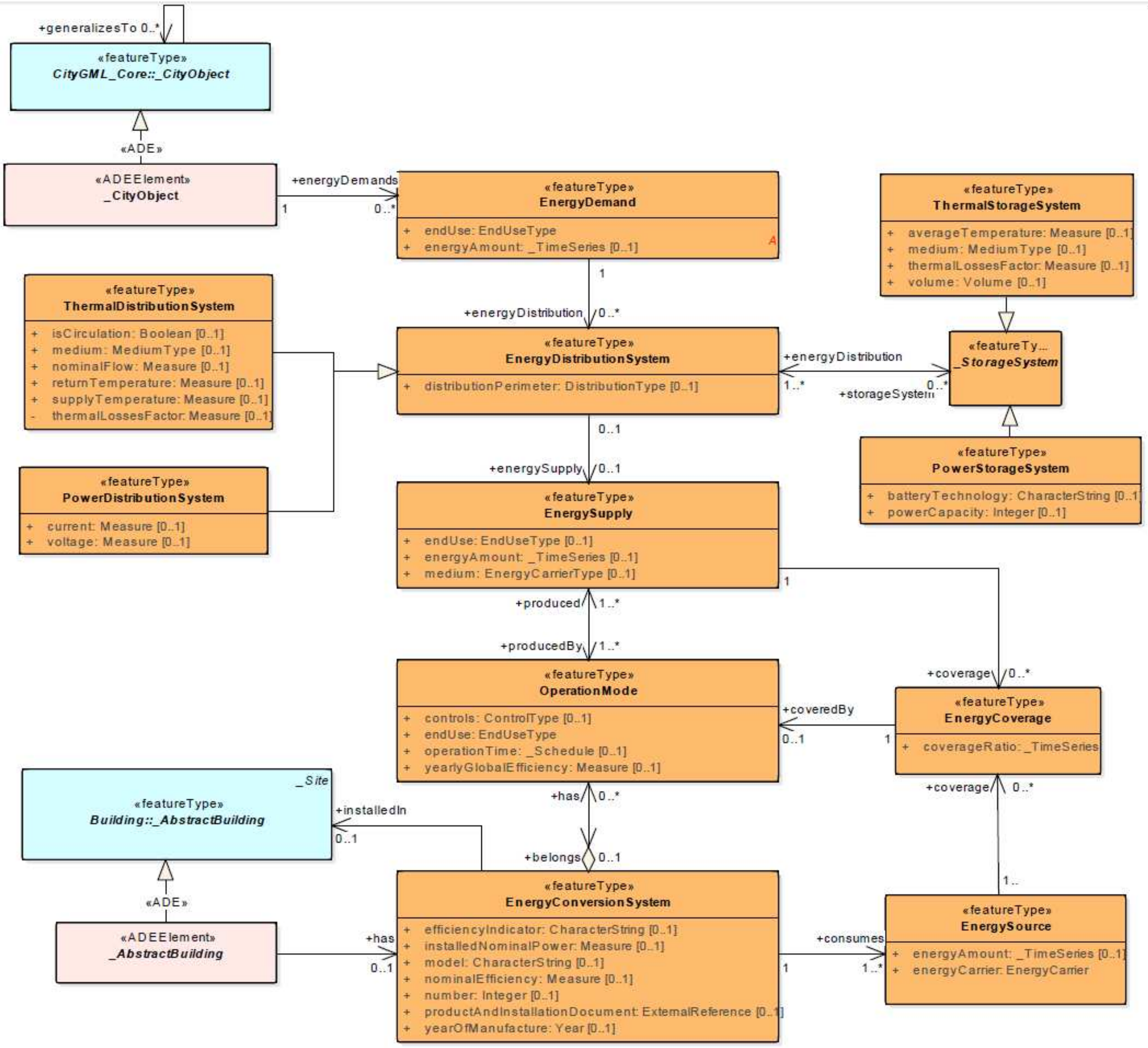

Figure 4 UML diagram extract of module Energy and System

TEST AND OPTIMIZATION PHASE

The development of this Energy ADE 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, this XML Schema is going to be tested within the numerous and diverse urban energy modelling and simulation tools used and developed by the different partners.

Among those, some are mere city model viewers, allowing for the navigation in the different city/building objects and attributes (EveCity of CSTB and FZKViewer of KIT). Some are urban energy platforms which assesses the building heating demands and refurbishment saving potential based on the monthly energy balance algorithm described in the norm ISO 13790 (SimStadt of HFT, EnergieAtlas of TUM, Sunshine Platform). They generally also calculates the related CO2 emissions and the renewable energy potentials (in particular solar). A Modelica library (AixLib of RWTH Aachen) is also used among the expert group to model dynamically the energy flows at urban scale.

Finally, the urban energy simulation software CitySim which calculates energy demands, energy supplies and radiation exchanges (solar and infrared) at hourly time step, is also going to integrate the CityGML Energy ADE as input and output files, and provide interesting feedbacks for its development.

This list of compliant urban energy tools is obviously not closed. Contributions and ideas from other urban energy modellers, which are developing other tools based on city models, are welcome. Only through this participative development process, this new CityGML Energy ADE can become a well-established Urban Information Model (UIM) serving as exchange support between different tools and expert fields, exactly like IFC and gbXML as BIM.

The present release is freely accessible on the SIG3D website: http://www.sig3d.org/citygml/2.0/energy/

CONCLUSION

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.
In order to become a well-established urban energy information model, this Energy ADE has been designed flexible, and compatible as far as possible with diverse urban energy planning and calculation tools, as well as with standard municipal databases and international data specifications like INSPIRE. The release of this first version is only the beginning of a long iterative process, where new active participants are very welcome. The test phase will allow confronting it with the challenges of software integration and real project issues.

Finally, although this Energy ADE is not formally a standard, its modular structure could favour a partial integration in the new CityGML releases (the module Materials, Time Series and Metadata are in discussion for the next release CityGML 3.0). In any case, a close collaboration with the OGC development team of CityGML is a key factor for the successful development of this new Energy ADE.

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