The Conception of an Urban Energy Dashboard using 3D City Models

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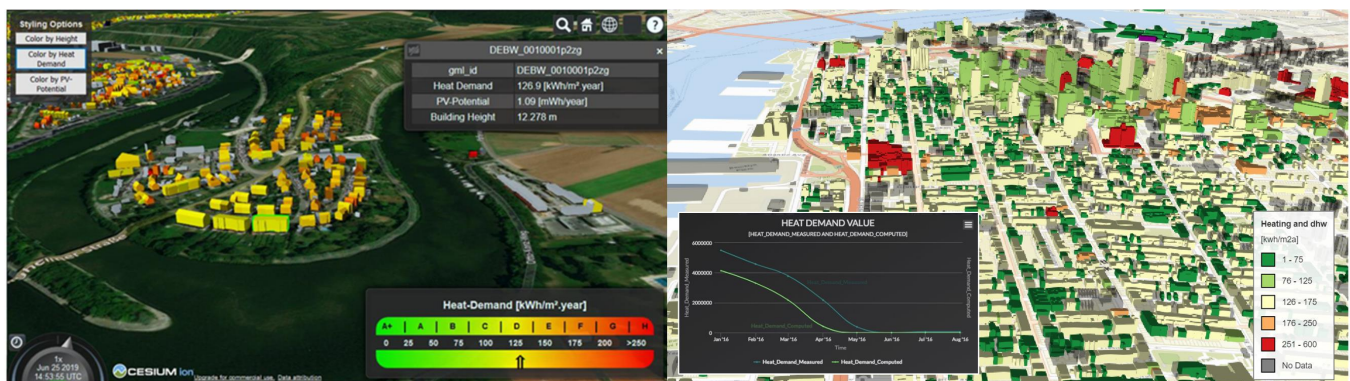Hochschule für Technik Stuttgart
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Figure 1: Web 3D visualization of urban energy data for Landkreis Ludwigsburg, Germany (Left) and Brooklyn, USA (Right)

ABSTRACT

In this paper, we present a concept for an urban energy dashboard built using different Open Geospatial Consortium (OGC) standards integrated with 3D city models. With cities continuously pressed to cut upon their carbon emissions, it becomes vital to visualize different energy data under one application. This perfectly fits our vision of developing an interactive web-based urban energy dashboard, which shows not only static data but also real-time dynamic data such as measured data from sensors, all integrated into 3D city models. Evolution of the mentioned dashboard is presented using three different case study regions based on data availability and its urban scale: 1) Landkreis Ludwigsburg - A district in Baden Württemberg, Germany showing static urban energy data of specific heating demand 2) Brooklyn - A borough in New York City showing urban energy data of specific heating demand (incl. domestic hot water) over a temporal resolution of 5 years and 3) Wüstenrot - A small municipality in Germany showing real-time dynamic energy data streaming from sensors integrated into a 3D city model. Such an interactive dashboard presents both static and dynamic urban energy data to the citizens and city administration in the most straightforward yet effective manner.

CCS CONCEPTS

• **Human-centered computing → Visualization toolkits**; **Visualization design and evaluation methods**.

KEYWORDS

Urban Energy Dashboard, 3D City Models, Energy Data Visualization, OGC Standards

1 INTRODUCTION

Rapid urbanization and its effect on climate change have been a continuous global threat. From an estimation (IEA 2016)[1], today, cities only accommodate half of the world population. Still, it is responsible for 70% of carbon emissions from the energy sector. As a result, cities are continuously asked to take the lead in the

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[1]Global Status Report 2017 published by International Energy Agency, United Nations

transition to low carbon neighbourhoods. A significant part of this transition involves substantial use of geospatial and urban energy simulation technologies.

Acceptance and realization of 3D city models, particularly in the OGC standardized and open data format of CityGML, have provided a significant boost in the development and visualization of urban energy data. While these 3D city models are extensively used for visualization as they are a georeferenced virtual representation of the physical elements. On the other hand, urban energy simulation software such as SimStadt uses these 3D city models to produce temporal energy demand profiles under different climatic conditions. Additionally, with the acceptance of SensorThings API as an OGC standard, the ability to use data from different sensor systems and integration with 3D City Models has become much more straightforward than before.

To investigate this further, in this paper, we present a concept for an urban energy dashboard built using different OGC standards along with 3D city models. Evolution of the mentioned urban energy dashboard is presented using three different case study regions based on data availability and its urban scale: 1) Landkreis Ludwigsburg - A district in Baden Württemberg, Germany showing urban energy data of specific heating demand 2) Brooklyn - A borough in New York City showing urban energy data of specific heating demand (incl. domestic hot water) over a temporal resolution of 5 years and 3) Wüstenrot - A small municipality in Germany showing real-time dynamic energy data streaming from sensors integrated into 3D city model.

2 BACKGROUND

2.1 Energy Simulation

SimStadt is a simulation Software from HFT (Hochschule für Technik Stuttgart). It uses modules from the Insel 8 [8] block diagram simulation system to create workflows to calculate specific energy data. The relevant workflows used in the project are for heating and cooling demand, as well as the solar potential for Buildings.
The calculations in SimStadt are based around a 3D city model in the CityGML data model. CityGML[2] is an OGC Standard to store and exchange city models and is based on XML. These models need to contain specific metadata, such as building age [5]. To enrich the CityGML models with missing metadata is described by Weiler et al. [10].

2.2 Web Visualization

For 3D geo-visualization, different tools are available. CesiumJS is an open-source 3D web-globe. CesiumJS offers a simple way to show 3D building models through the web. Contrasting to the purpose of storage and exchange of the CityGML model, CesiumJS developed 3D Tiles with web visualization in mind. To convert the CityGML data to 3D Tiles, different tools, such as GeoToolbox[3], Feature Manipulation Engine (FME)[4], or virtualcityPUBLISHER, can be used. As part of Cesium ION, CesiumJS itself provides a service to convert, but no open source tools were available at that time. For the project, FME showed the best results. In addition,

CesiumJS's build-in timeline functionality gives the possibility to show time-specific data, which is essential for the project. For displaying graphs, the Highcharts library is used.

2.3 Sensor Data Management

To work with the sensor data, the SensorThings API is an OGC Standard since 2016 for managing the heterogeneous sensor data working with the REST principal in a JSON format [4]. The SensorThings was evaluated and compared with the OGC Sensor Observation Services, and the result showed the SensorThings advantages in terms of connectivity and simplification [7]. Moreover, the standard had been applied in multiple complex cases and has shown that it transfers data very efficiently [2, 3, 9]. Accordingly, we implement the sensor server based on the SensorThings standard.

2.4 Database Management System

The project requires two different datasets to be stored in a database, the CityGML model, and the results out of the SimStadt workflow calculations. There is a myriad of Database management systems [1]. For the project specifically, a relational DB is preferred to a file-based system such as MongoDB [12]. The 3DCityDB is a solution to store CityGML data in a database [13]. It is an open-source schema for Oracle and PostgreSQL/PostGIS. For the project, the PostgreSQL database management system is used.

3 CONCEPT

This paper aims to present different energy scenarios to the public in an understandable fashion. They contain the specific heating (status quo and retrofit) as well as the EUI (energy use intensity). Users can then easily compare it to their own homes by the square footage. The best concept for visualizing this on the 3D globe is to apply it to the buildings. For this reason, the results are classified into six groups. The buildings are then colored in correlation to the respective groups. One aspect of this project is to show the evolution of the specific heating demand over five years.
For users that are experts in the field, more information needs to be conveyed. The visualization is, therefore, extended by a dashboard that shows information about the calculated and measured data. To achieve this, the following concept has been devised. It requires manual input from experts at the beginning of the process to create different scenarios of energy usage or refurbishment strategies. These scenarios are then calculated in the SimStadt software and exported to a PostgreSQL Database. The visualization is done in a CesiumJS web globe, which accesses the values in the database and presents it to the users, which include the general public and experts in the field, alike. To visualize the time relevant aspect, the values are shown in succession to convey the change and improvement of the heating demand in the best possible way. The measured data for the dashboard is managed with a dedicated Server for Sensor data.

4 METHODOLOGY

In this paper, we implemented a platform to visualize the temporal urban energy with 3D city models on the web-based application as a proof-of-concept. The overall system architecture of this platform is concluded in figure 2, which consisted of five main elements,
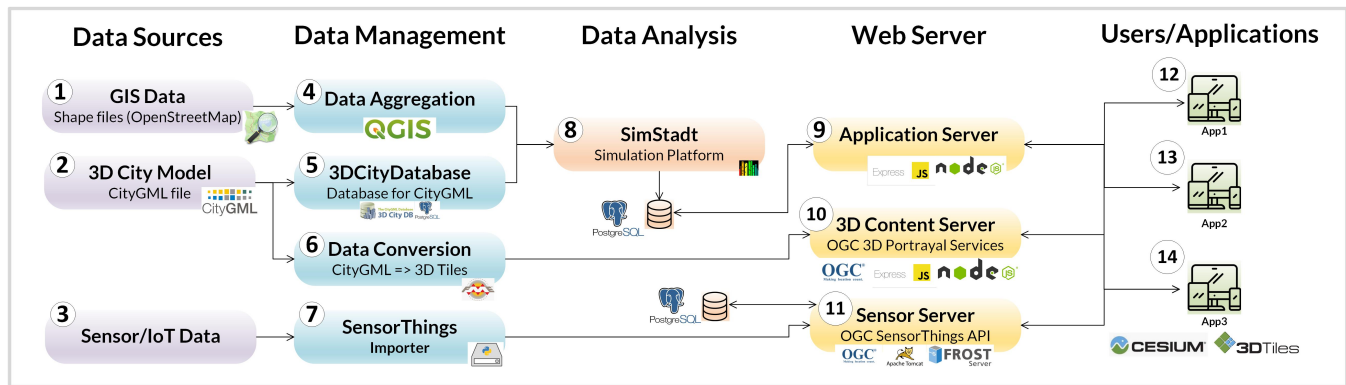

Figure 2: Overall System Architecture

including 1) Data Sources, 2) Data Management, 3) Data Analysis, 4) Web Server, and 5) Users. The features of each element are explained as follows.

4.1 Data Sources

4.1.1 GIS Data. (figure 2-1)
The GIS data is relevant to fill the missing information of the 3D building models by using the geospatial aggregation method in the GIS software. The primary data source is coming from the OpenStreetMap service from GeoFabrik[5].

4.1.2 3D City Models. (figure 2-2)
The 3D city models in CityGML format are the primary source used in this research. For the visualization purpose, these CityGML datasets are converted into 3D Tile format as a service hosted with the OGC 3D Portrayal Service standard. For the energy simulation, the CityGML is imported to 3DCityDB for the SimStadt tool. Our 3D CityGML models in this research include 1) CityGML of Landkreis Ludwigsburg provided by Landkreis Ludwigsburg, 2) CityGML of Brooklyn borough extracted from the open data provided by DoITT[6] and 3) CityGML of Wüstenrot provided by Landesamt für Geoinformation und Landentwicklung (LGL) Baden-Württemberg, Germany

4.1.3 Sensor Data. (figure 2-3)
In this study, several measured sensor data from the study area of Wüstenrot are focused and used which includes the open weather data from the German Meteorological Service[7] and solar energy production from iPlon[8].

4.2 Data Management

4.2.1 Data Aggregation. (figure 2-4)
The data aggregation is applied to make use of the geospatial dataset from OpenStreetMap, we used the spatial aggregation method to integrate the relevant attribute information of the 2D building foot and points of interested to the 3D building model. Firstly, the FME is used to extract the building footprints of the 3D

city models as polygons and, then we used the QGIS software to do the spatial aggregation. After that, the building footprints with all aggregated data are converted back to CityGML city models for simulation operation by SimStadt.

4.2.2 3D City Database. (figure 2-5)
We used the 3DCityDB to store the 3D CityGML Data in a database system. The installation requires a PostgreSQL instance with the extension of PostGIS. The 3DCityDB came with importer and exporter components, which simplifies the workflow. In the project, two settings in the importer were essential, the bounding box and the feature classes. They allowed filtering the buildings of specific areas that were needed, since they are the only feature class that should be calculated with SimStadt.

4.2.3 Data Conversion. (figure 2-6)
In order to visualize the 3D city model on the web client, the 3D city model in CityGML has to be converted to files with the format that fits for optimal web-based visualization. In this research, we converted the CityGML to 3D Tiles format using FME (Feature Manipulation Engine) Workbench software. The tool allows us with a feature to read CityGML file and write the output as 3D Tiles file format in an easy way.

4.2.4 SensorThings Importer. (figure 2-7)
The SensorThings importer [6] is implemented using Python in order to clean and parse the heterogeneous sensor data from several different formats and import to the SensorThings sensor server (figure 2-11).

4.3 Data Analysis
The modeling process in SimStadt (figure 2-8) is separated into different workflow steps. Initially, CityGML models are imported and checked for its geometrical integrity. Ones passed, SimStadt then searches for metadata of building function and year of construction for each building within the passed CityGML building dataset. Attributes of the year of construction and building function forms the basis of building usage and building physics module of SimStadt which is a library of building construction material and building energy properties for different building typologies based on its year of construction [5]. This library is specific for a country and can be

easily extended to building typologies of different countries. Based on the location of the input CityGML file, which are defined by coordinates and coordinate system (EPSG code), SimStadt derives its relevant weather data from SimStadt embedded weather database. Considering the building geometry analysis, building usage-, building physics library and weather data, SimStadt now calculates the monthly heat energy demand and EUI. The output data in the form of a CSV format is then imported into the PostgreSQL database and provide the data to the user as a service which is connected to our application server (figure 2-7) in the webserver section.

4.4 Web Server

4.4.1 *Application Server.* (figure 2-9)

The application server is built up with the `Express` framework[9] on top of the Node.js server which allows easy communication to users. Also, with `pgPromise` library added to the server, it will enable the webserver to communicate and let users query the data from the PostgreSQL database. Additionally, this Node.js server contains the modules and dependencies to run the CesiumJS 3D web application.

4.4.2 *3D Content Server.* (figure 2-10)

In addition to the application server, we implemented our 3D geospatial server according to the OGC 3D portrayal services as a protocol to deliver these contents in a standard way. This server was also built based on the Node.js with the Express framework.

4.4.3 *Sensor Server.* (figure 2-11)

To handle the measured data, we use the FROST SensorThings API [10] implementation on our server using Apache Tomcat. The sensor data is imported to this server with the SensorThings importer (figure 2-7) The web application can communicate with the SensorThings Server directly with the `HTTP GET` request. The resulting responses are in developer-friendly `JSON` format.

5 USE CASES

5.1 Landkreis Ludwigsburg

Landkreis Ludwigsburg comprises of 18 towns and 21 municipalities. For each of these towns and municipalities, using 3D city models, heat energy demands were calculated with SimStadt using German building usage and physics library. Integrating these energy demand results back into CityGML building files and converting terrain datasets of the area to a quantized mesh terrain allows the data to be shown in a CesiumJS application (1 (left)). Developing such a simple web application helped the climate manager of Landkreis Ludwigsburg to formulate a long term climate protection concept for Ludwigsburg district.

5.2 Brooklyn

The 3D web application in figure 1 (right) shows three different energy data sets for entire Brooklyn. These are the heat energy demand based on the actual values and a refurbishment strategy (retrofit). Additionally, it also displays the EUI over a period of five years. This application allows users to investigate the different heat demand or energy usage scenarios according to the building size and structure. These scenarios are created by experts according to refurbishment strategies. They are also a benefit to city planners to handle and monitor the urban situation and future planning scenarios; for example, suggesting which building refurbishment provides the most significant benefit. The temporal data gives urban planners and managers an impression of the time that has passed and the changes in energy usage that occurred. The time frame of the calculated data is from January 2011 to December 2016.

5.3 Wüstenrot

For the case study of Wüstenrot (figure 3), which is a small municipality in Germany, different sensor data is used for visualization purposes. The sensor data is focused around multiple solar panels and an agrothermal plant. It is displayed in a dashboard with different graphs that are connected to specific locations or buildings. This is especially valuable for the municipality itself since it wants to present the development to the residents. This concept developed in the Smart Villages project will possibly be opened up to more and more municipalities to register their sensor data.

6 CONCLUSION AND FUTURE WORK

The goal of creating an interactive dashboard to visualize the urban energy information in different study areas has been achieved. The results will be evaluated, and more components will be added to the dashboard in future work. In the case of Wüstenrot, this process has already started.

At the HFT, a web version of SimStadt is in development. With this, the web globe can directly communicate with the SimStadt API to forgo the way over a database. A prototype connecting SimStadt web API directly to the web globe has also been researched [11]. As the 3D web visualization tool, we used the CesiumJS as the framework for the web globe. However, there are other 3D virtual globe frameworks such as World Wind Globe, ArcGIS for Javascript, Mapbox, Deck.gl, and Three.js[11], which have to be investigated in the future. For the 3D building models, Esris i3s format will also be evaluated and compared to the 3D tiles format from the perspective of web-based visualization performance. The PostgreSQL database with the 3DCityDB schema provides the opportunity for ADEs (Application Domain Extension). One such ADE that is interesting for storing Energy relevant data is the Energy ADE. It should allow for better integration between the energy data and the 3D City model. In future work, this possibility will also be examined.

ACKNOWLEDGMENTS

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[10]https://github.com/FraunhoferIOSB/FROST-Server

[11]https://worldwind.arc.nasa.gov/,https://www.mapbox.com/,https://deck.gl/ https://threejs.org/

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7 APPENDICES

A ADDITIONAL FIGURES
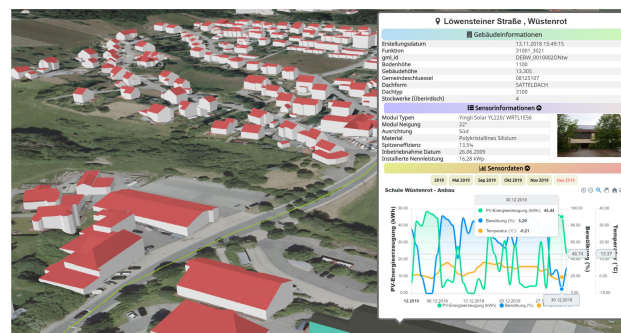
Figure 3: Web 3D visualization with dashboard showing building energy production from a solar panel and enviromental data Wuerstenrot, Germany