Integrated Energy Monitoring and Visualization System for Smart Green City Development

Designing a Spatial Information Integrated Energy Monitoring Model in the Context of Massive Data Management on a Web Based Platform

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Abstract. U-Eco City is a research and development project initiated by the Korean government. The project's objective is the monitoring and visualization of aggregated and real time states of various energy usages represented by location-based sensor data accrued from city to building scale. The platform's middleware will retrieve geospatial data from a GIS database and sensor data from the individual sensory installed over the city and provide the browser-based client with the accommodated information suitable to display geo-location characteristics specific to the respective energy usage. The client will be capable of processing and displaying real time and aggregated data in different dimensions such as time, location, level of detail, mode of visualization, etc. Ultimately, this system will induce a citizen's participation with the notion of energy saving, and be utilized as an interactive energy management system from general citizens to authorities who are responsible for designing or developing city infrastructure. The platform's middleware has been developed into an operative, advanced prototype, providing information to a Web-based client that integrates and interfaces with the Google Earth and Google Maps plug-ins for geospatially referenced energy usage visualization and monitoring.

Keywords. Energy Monitoring; Data visualization; Smart Green City; Spatial information model; EnerISS; Social Sensing.

1. Introduction

The objectif of this research is to build an energy management system called EnerISS (Energy Integrated urban planning & managing Support System). The research initiated from the idea that the city can provide a systematic infrastructure that delivers extra power such as electricity or heat to demanding areas through an intelligent power network. In this context, building up an effective energy-monitoring tool is one of the most important tasks to implement for the EnerISS scenario. The basic assumption is that the system is not only used by energy management specialists but also by the general energy consumer. We deliver the information both to the non-professional user and professional energy manager to enhance the notion of energy-aware consuming and to support more strategic and efficient energy usage decisions. Furthermore, by accumulating periodical data, the system will also be able to provide a statistical foundation to predict and to design the future energy plan. In this context, we present a prototype of an energy monitoring system called EnerGIS (EnerISS Viewer in Figure 1). It is a Web-based rich-internet application (RIA) integrating a 3D geospatial viewer based on the Google Earth platform and Google Maps components with additional data visualization modules. Combining city information model data from the database, energy consumption data (through a sensor network), and environmental GIS data, it builds up its own monitoring database. The EnerGIS tool is powered by its middleware engine that has been conceptually designed and developed by our project partner, a software development and strategic consulting company specializing in geospatial systems, location-based as well as serious game services. In the long run, this system will also provide an intelligent analysis and prescription system based on a business rule engine so that significant decisions for energy management can be suggested through user-friendly interfaces meeting multiple viewpoints from various stakeholders including residents.

Figure 1 illustrates the system architecture of the EnerISS solution which integrates modeler, viewer (EnerGIS), database, and data acquisition module. The EMS (Energy Management System) will control the operation of power plants based on the rules generated from the interaction between the solver and evaluator. They can predict the energy demand from E-GIS data, enabling in-time planning of energy supply through the EMS.

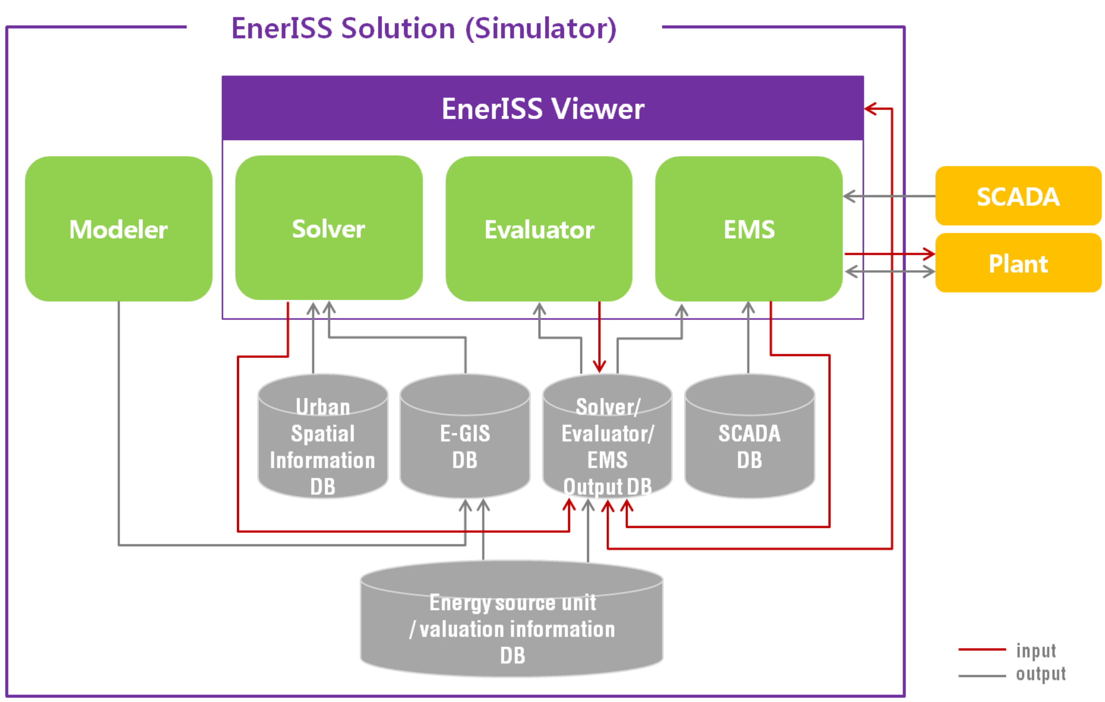


Figure1 EnerISS Solution, which has the following four different modules, interacts with the urban spatial information database, E-GIS, SCADA database and the energy source unit / valuation information database: Modeler, Solver, Evaluator and EMS.

The modeler allows interactive 3d modeling of urban space, and automatically transfers the model data to the solver, and the solver estimates energy demand of the city by combining the e-GIS data and the geospatial data. The evaluator, which analyzes energy usage to deliver the most effective energy supply strategies, suggests feasible energy plans by interacting with the solver / evaluator / EMS integrated database. Meanwhile, the viewer visualizes all these information in real time [Figure 1].

2. Related Work

The most relevant work in IT technologies is the "smart grid [1]" that includes an intelligent monitoring system keeping track of all electricity flowing in the system: (Amin, 2005; Kai, 2008). The technologies enhancing energy saving can be divided into the following two areas. The first area only informs about energy consumption data related with usage patterns in order to motivate citizens to save energy (smart meter, Google PowerMeter [2]). The second area does not only monitor the energy consumption but also controls the power source in a very interactive way: (Cai, 2009; Motegi, 2009). A further area is, nowadays, expanding further to cover the life and public design in very emotional aspects like ambient lighting: Bartram (2010). IBM has announced recently that it will soon publish a SimCity-like serious game named CityOne [3] that will allow to process real-world data and to "play out" possible and future results – an approach we assume will demonstrate how games as motivational and scenario systems can be taken advantage of to tackle real-world challenges and to let people participate in solving these challenges. In comparison, our client and middleware prototypes already integrate typical social game mechanisms such as leader-, and loserboard functionalities, to let users find out how their geospatial region has used energy over time. More game-like features are planned for future iterations.

3. Research Objectives and Method

It is crucial to involve citizens who consume energy in order to build up an energy-ecosystem consisting of energy suppliers, energy managers, policy makers and citizens: Odum (1976). Constructing these participatory environment, we can eventually convince energy consumers to achieve the targeted level of energy saving and reduced CO_2 emission. With these demanding specifications, we identified the following characteristics for our solution:

- Web based platform
- Intuitive statistical data visualization
- Real-time based sensor data collection and data aggregation
- Dynamic data loading and visualization
- Extensible city information

We used the 3D urban environment in the Google Earth plugin and designed various visualization alternatives to support various user scenarios. In this context, we found critical research issues with regard to the system we wanted to achieve, defining the following research objectives:

- Optimized data structure model of urban environment
- Data optimization for 3D city representation

- Visualization strategy

3.1 Urban Data Structure Model

The existing GIS system and diverse Building Information Model (BIM) technologies can represent the 3D geological environment with semantic information, and we might utilize those existing technologies for a small test bed environment. However, there are distinctive limitations to the adoption of the technologies into our energy monitoring system, because the GIS system uses a pre-made 3D model that cannot be easily extended and modified after data is imported into our system. Additionally other BIM technologies that have detailed information on buildings are also not suitable to be easily adopted because of the closed nature of their data querying characteristics, since the data would have to be retrieved on a selective basis due to the huge amount of information at the city scale. So we had to design an alternative solution, which is sustainable for ubiquitous (WWW) access of future users.

3.2 Data Optimization for 3D City Representation

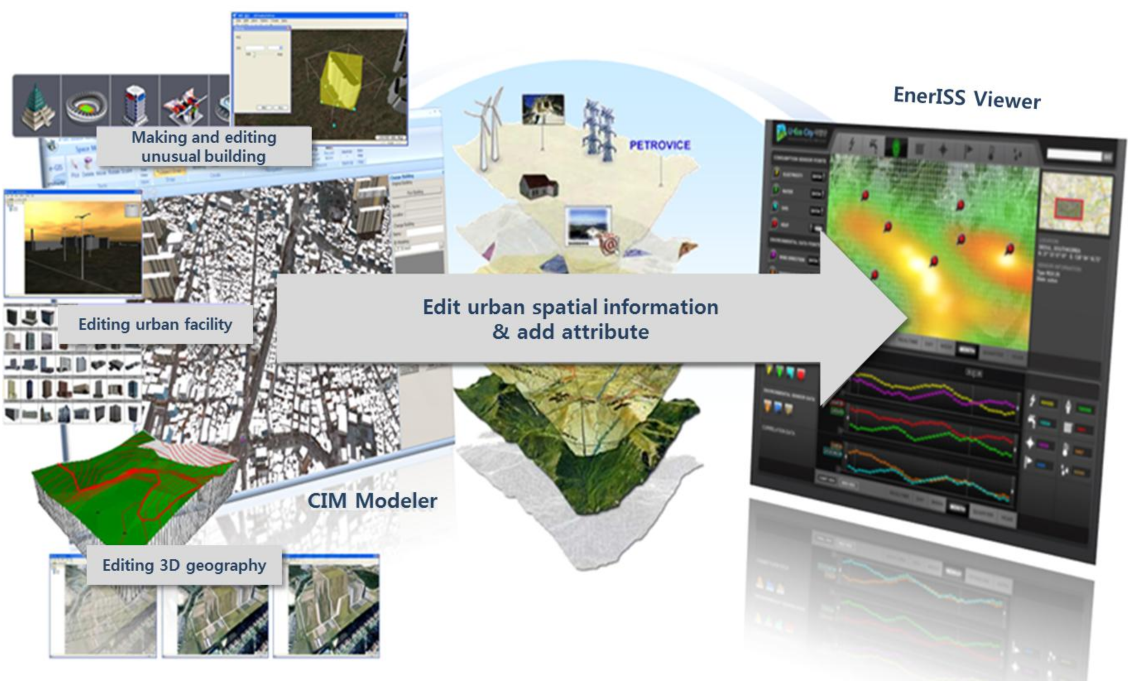


Figure 2 EnerISS modeler supports diverse editing functions optimizing the urban spatial information models

This simulation platform deals with massive data volumes due to the huge number of buildings, the city environment model and the ongoing data collection within short periods of time. In order to deliver large amounts of GIS data and build the model more efficiently, we adopted the Google Earth plugin, which is a virtual globe, map and geographic information program that was originally called EarthViewer 3D created by Keyhole, Inc. The main data format processed by Google Earth is named KML (Keyhole markup language). It has been submitted as a standard proposal to the Open Geospatial Consortium (OGC) and – since version 2.2 – has become an offical standard.

The EnerISS Modeler allows parametric generation of 3D building models from GIS data with the option of manual editing. The KML file was extended to accommodate additional attributes and LOD control scripts when it was conceived at the beginning [Figure 2]. However, the final design of the system maintained the original format without additional information as the middleware engine generates scene modes in response to the user interaction. In this way, the visualized data has a small footprint and does not require complicated interpretation of scripts on the client side.

3.3 Visualization Strategy

Citizen participation scenarios in energy saving is one of the main subjects of this project from the initial moment. It requires an intuitive, easy-to-use interface and a suitable representation method to assist user interaction with the system. Therefore, diverse ways of visualization have been tried [Figure 3] and several effective ways of representation were implemented:

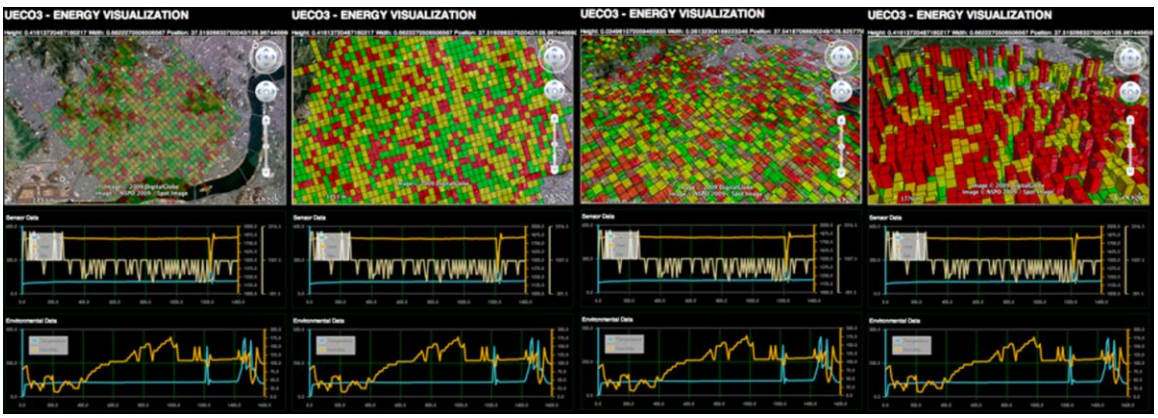


Figure 3 Several concept types for cell data visualization. The images shows different types of cell data representation with the following attributes: color, height, 3D-geometry and alpha value. Also note that the Google Earth visualizations are always accompanied by chart representations that allow for representations of energy usage over time.

4. Implementation

4.1 Overview of Design of Energy Visualization System

The new trend for wide area geospatial information systems is web based three-dimensional city models interacting with geospatial information and mash-up services, which contain diverse multimedia information (Wong, 2009). In this context this system is designed to support a dynamic 3D city environment, which is based on the Google Earth plugin. Delivering energy usage data in a complex city model especially requires well-organized spatial structure in accordance with different LODs, because using various view-dependent LODs helps to decrease the complexity of the 3D urban environment representation as it moves away from the viewer or according to other metrics such as area, block and building importance, eye-space speed or position. Therefore, we planned to set up five different levels of detail: area, block, building, floor, and unit, and for this test bed platform, we simplified these 5 LODs into 4 LODs that are grid, cell, building and floor [Figure 4]. “Block” level of detail originated from the e-GIS system that is based on mesh cell and consists of 200m x 200m. This grid cell represents the wide-area of urban scale, like a pixel map. When we navigate into the building scale, the “building” level of detail is activated automatically and shows each building’s energy usage by different colors. Accordingly, zooming into the “floor” level brings up details on the floor scale. The “floor” level of detail that is the highest LOD is interactively shown by user request when the mouse is double clicked on the aimed building in order to optimize real-time data flow which has relatively large amounts of data depending on the building scale.

Figure 4 LOD scheme by KML 1. Building model in Grid cell, Grid cell has link to each building 2. Building unit: base area x number of floors, each Building has link to floors 3. Floor level of detail

Corresponding with these scenarios, we suggested “a middleware engine”, which aggregates the sensor data and city information to build up an optimized database that allows for fast and efficient generating of dynamic visualization from web based requests [Figure 5].

The middleware engine has a database and a visualization component. All of the consumption and environmental data, which will be provided by the sensor network, are accepted through a Restful interface (Representational State Transfer) and aggregated into the middleware engine, and the data processing component placed in the middleware engine retrieves the sensor data to aggregate them continuously. The server will combine geospatial data with energy consumption and environmental data in real time, transform the raw data into the KML dialect and deliver it to the client in a compressed format (KMZ files). Therefore when the end user requests the data, the KML service API, which is embedded in a web-browser, can directly deliver the data set from the server, without complex data processing, and visualizes it immediately.

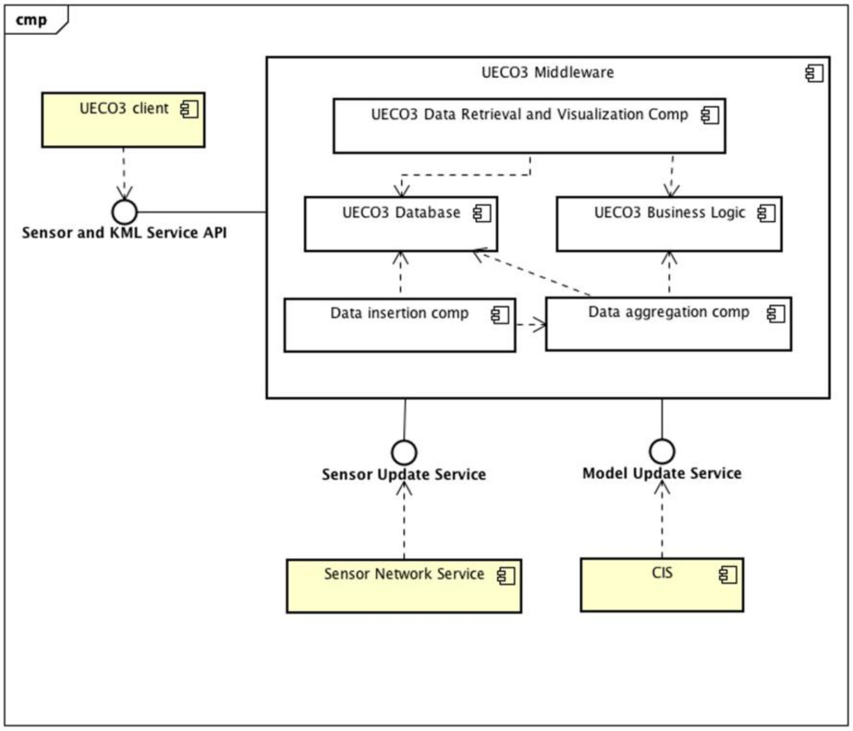


Figure 5 Middleware engine components and connections to other services

4.2. Test Bed for Sensor Data Visualization in the Google Earth Component

Before we practically started to develop Urban Integrated Enegy System (UIES) platform, we made a pilot system to test several technical issues that mainly concern real time sensor network and some representation method with the Google Earth plugin [Figure 6, 7]. Ten wireless environment sensors were installed in a building that is located in Dongtan Korea, and collected the following data: CO2 density, temperature and humidity in real-time. From this pilot platform, we found several issues concerning wireless sensor networks, extensive data aggregation and the visualization within the Google Earth plugin.

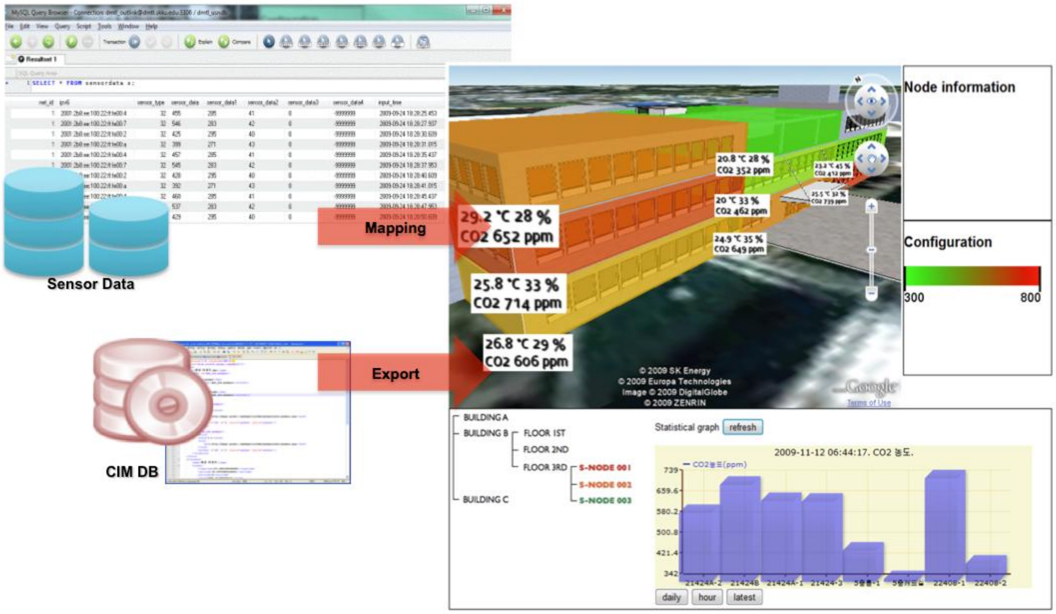


Figure 6 The pilot system of visualizing real time sensor data using the Google Earth plugin

Figure 7 Raw sensing data is visualized in diverse ways: a Bar graph and line graph, daily, hour, and latest time selections.

First, the wireless network between sensors sometimes causes trouble inside buildings due to the walls blocking signals. Therefore it is crucial to analyze the internal building characteristics before installing sensors. Second, with regard to the periodical data that will be collected by the sensors, we needed to constantly aggregate and optimize the collected data in order to be able to deal with the massive amount of data being fed into the system over time. This has to be done by designing aggregated table or data cubes and processing the data coming from upstream systems in an asynchronous way. The system therefore has to implement the typical functionalities of a data warehouse.

4.3 Urban Data Structure Model for Energy Visualization

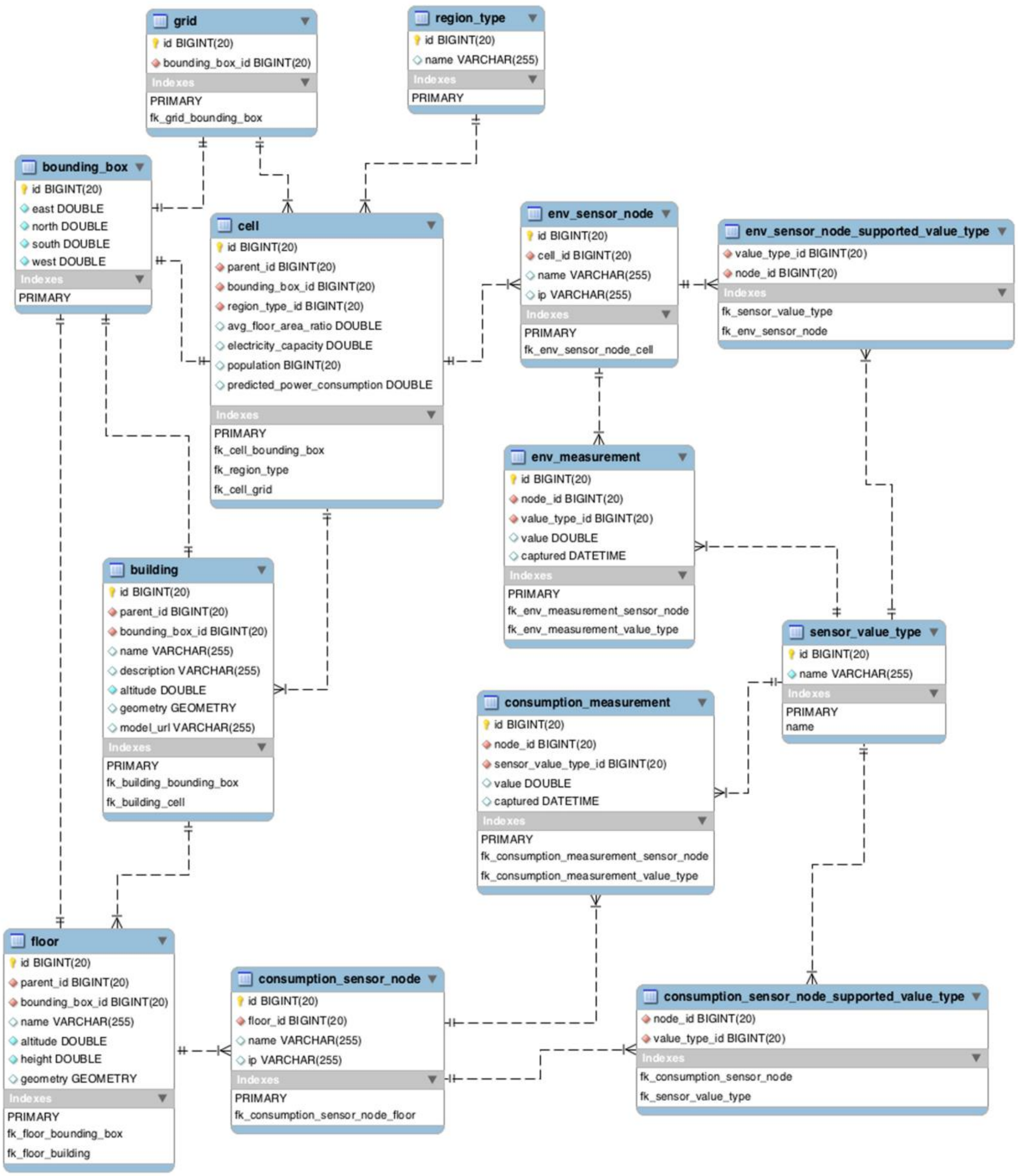


Figure 8 Optimized data structure for urban spatial information

Implementation of the energy visualization via a web based client which dynamically supports loading the preprocessed data and serves information visualization in real time by calling of complex objectives fully and consistently will realize our ambitious concept. A well-designed data structure of the urban environment enhances the system performance and data representation method [Figure 8]. When we built up the system, it seemed not suitable to simply utilize existing urban data models because of the data optimization issue. Therefore we built up the data structure with UIES customized attributes. In the geospatial dimension, we worked with several entities that match the various levels of details (LODs). Each entity apart from the highest one in the hierarchy has a parent entity (e.g. a cell entity consists of several building entities, which all have the cell entity as parent) in order to be capable of performance and precise data traversal up and down the hierarchy. Every geospatial entity disposes of a Bounding Box object, so that it can be clearly identified by its most simple geospatial attributes (i.e. latitude and longitude for all 4 sides of a proposed rectangle).

Despite their similar structure, we have decided to store consumption and environmental values in two different tables due to the necessity of performance when dealing with huge amounts of data (within our tests we realized that especially the consumption values aggregated to thousands of rows within just a few minutes). The measurement values represent the data provided from the sensor network. Therefore each sensor value has an association to the respective sensor node, from which the data was coming and harbors properties such as the time at which the values has been captured, the value itself and the type of the value. This design makes it possible to have strong referential integrity for the accrued data and be expandable for future requirements such as more kinds of data coming from the sensor network.

4.4 Large Data Treatment

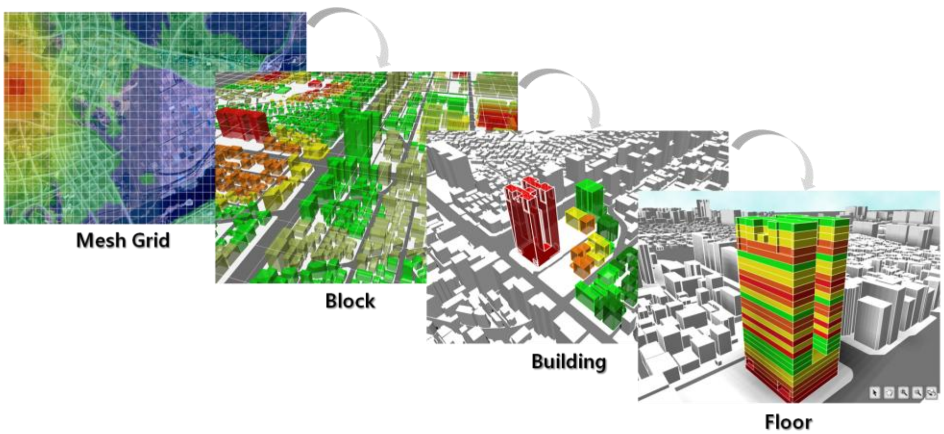
After our first stress tests, which were limited to data generation for just one grid (the test bed area as described above) we realized that the performance of querying data on a real-time basis below the grid level will very soon become unacceptable for the end user, even though the established mechanism of dynamically reloading data in real-time according to user actions helped in the beginning to limit data traffic to the data which was actively requested by the users. With consumption sensor data possibly being provided every 10 minutes and environmental data being updated every hour, the amount of data collected over the course of a single day was so huge that the request of this data let alone the real-time preprocessing (algorithms building averages, ratios or accumulations) forced the browser application and their respective AJAX functionality to slow down in an unacceptable manner.

The time dimension also mandated a powerful mechanism on the server side to aggregate the incoming data feed, especially when time granularity was decreased (up to year level). Therefore the middleware had to utilize a mining component, calling this component whenever new data arrived, so that the mining component could process the incoming data and populate the aggregation tables accordingly. Data processing of the mining component was done in an asynchronous way so that performance of accepting and collecting sensor data from the sensor network would not be affected by the resource consuming task of building data suited for the aggregation tables. The aggregation tables were build for 2 dimensions: the LOD-dimension, where data was aggregated on building and cell level, and a time-based dimension where data was aggregated per hour, day and month. With this warehoused data the front-end application was able to request data from a specific region, with the server side components balancing out the best way to collect and deliver the requested information.

4.5 Representation Strategy with Diverse Visualization

1. Choropleth map in 3D urban environment

According to the current distance to the earth's surface all cell data is displayed as a choropleth map. We defined the LOD in the following four steps: mesh grid, block, building and floor levels. The given LOD, mesh grid, block, and building, specify physical boundaries in an urban area. The “block” level of details considers semantic regional boundaries in order to analyze customized area [Figure 9].



[Figure 9] Level of details: “Mesh grid” is divided by e-GIS system unit that is based on mesh cell and consist of 200 by 200 square meters. “Building” LOD defines each building unit and “Floor” LOD defines each floors.

As the distance to the earth’s surface becomes closer, the client automatically switches to a higher LOD (here the building or floor level) and buildings are displayed three-dimensionally in a specific color, with the color red denoting a consumption relatively located in the upper 33%, yellow for a consumption value located in the middle 33% and green for a value in the lower 33% [Figure 10].

Figure 10 Choropleth map in different level of detail: Block, building and floor

2. Display of Charts for a Selected Data Type

When a data type has been selected and a cell on the map is double clicked, the user can have the corresponding values displayed in time via a line diagram. The bottommost panel on the left side of this section lets the user put those values in correlation. The last 2 clicked items will be brought in correlation and be displayed in the third and bottommost line diagram. The following chart shows a simple correlation between two selected factors [Figure 11]. In the diagrams a user can juxtapose two distinct series of consumption and environmental data, with the values for consumption data over time shown in the topmost diagram and the values for environmental data over time shown in the middle diagram. A trend analysis is then performed, which puts the selected

environmental data curve into correlation with the selected consumption data curve. Thus the bottom diagram shows the correlation intensity between the two selected curves above: the higher the value in the third diagram, the stronger the correlation between the two selected values above will be. In the example shown in Figure 11, it is clearly display that the correlation between humidity and heat consumption gets lower as the two topmost curves head for different directions. The correlation analysis can be performed between each environmental and consumption data series simply by clicking on the symbols to the left of the diagram.
Furthermore, by implementing a business rule engine, we will not only execute data correlation between sensor and environment data but also expect to extract meaningful mining output that we didn't assume before.

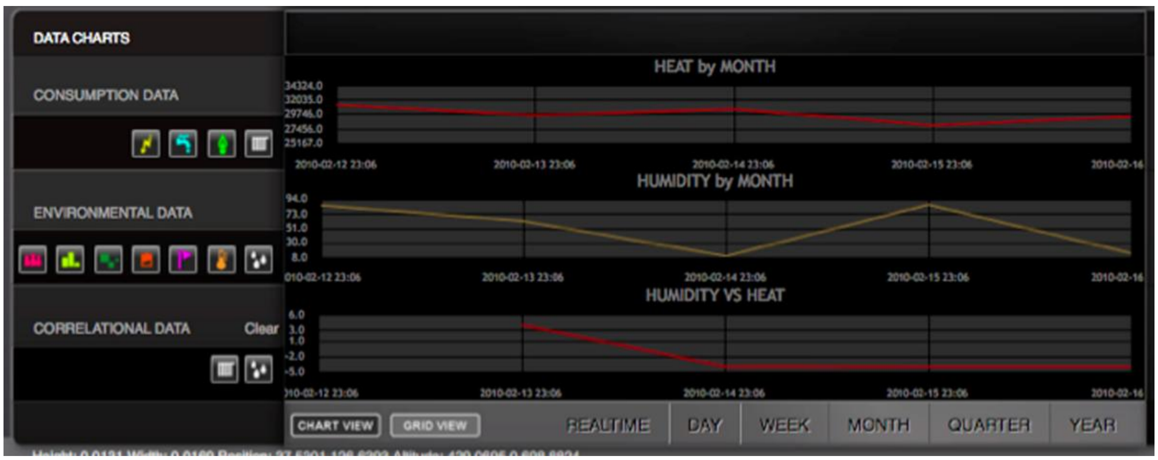


Figure 11 Line diagrams for the different data type series and their correlations.

3. Diverse Representations

If users prefer to have the leaderboards shown in the course of time (with monthly granularity), they can select a tabular view and get forwarded to a different web page that displays both the leaderboard for best performance as well as the leaderboard for the worst performance over the last year for the selected data type. If the user selects to have the leaderboard displayed in the Google Earth plug-in, a pillar for each cell is displayed, with the height and the color both denoting the rank in the leaderboard. The tallest pillars are always green colored and show the "leading" cells, whereas the lowest pillars are colored red and show the cells, which consumption value has evolved the worst within the given month [Figure 12].

Figure 12 Leader as tabular view and leaderboard view within the Google Earth plugin for Electricity

4. Integration of Social Sensors

So far, we mainly used mash-up methods to support better decision making in order to manage an effective energy supply and demand level which is based on analyzing temperature, humidity, time and other crucial values. Meanwhile, [Figure 13] shows another trial which displays sensing data by the mash up method. We are planning to implement diverse social networking services (Twitter, Facebook, etc.) into the EnerISS solution that enables interaction with the public, and it will also be enhanced by a human centered sensing environment.

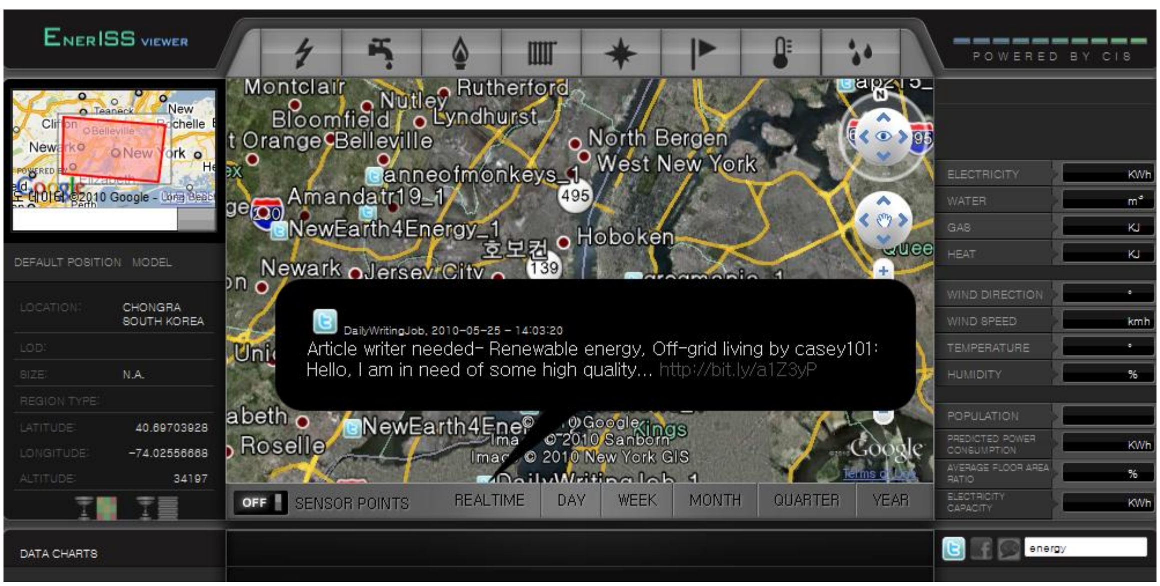


Figure 13 mash-up visualization of the social sensing environment

5. Conclusion

Currently, we design our own database structure to enhance system performance and to implement a customized middleware engine to optimize the visualization method, which is mainly based on a LOD strategy. In this process, we acquired knowledge for databases that manage large amounts of data that are continuously aggregated by time flow, and for a system architecture that represents an energy driven urban environment. Furthermore we acquired the know-how for a web based management system, which delivers sensor data, statistical data mining and diverse information visualization.

6. Future Work

This research represents an energy monitoring and visualization system and will implement an interactive energy management system for the next step. Based on the current development, the mining engine, which supports comparison between selected factors, will be improved by implementing a business rule engine, which can automatically discover significant knowledge from the database. Furthermore, the LOD capabilities will be elaborated from floor level to unit (room) level, which will empower the system to evaluate energy efficiency respect to the building direction, materials and other environmental factors. In addition, it could be possible to integrate further mechanics, e.g. stemming from games, to motivate users to participate in such a system.

7. Acknowledgement

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