# DEVELOPMENT OF A CITY INFORMATION MODEL TO SUPPORT DATA MANAGEMENT AND ANALYSIS OF BUILDING ENERGY SYSTEMS WITHIN COMPLEX CITY DISTRICTS

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## ABSTRACT

Urbanization causes increasing energy demand within cites. To identify energy saving potentials on city district scale, integral planning approaches are necessary. This paper describes the development of a city information model (CIM) with focus on buildings and energy systems. It accounts for different building and energy system types plus geometry, building physics as well as occupant information. The CIM structure has been implemented on a PostgreSQL database (DB), which has been linked to a geographic information system (GIS) to enable graphical data analysis and modification. Considering data uncertainty, the CIM structure supports a simplified city district modeling. Within a case study, DB and a Python tool are used to parameterize buildings for dynamic simulations to estimate the state of retrofit.

*Keywords: City district, CIM, GIS, energy systems, PostgreSQL*

## INTRODUCTION

The megatrend urbanization causes increasing needs within cities. Especially rising energy demands have to be covered. This concentrated energy demand leads to high greenhouse gas emissions within cities. Urban areas are responsible for around 70% of emissions, but only cover 2% of land mass [1]. Therefore, they offer great potential for emission reduction. However, the identification of options for greenhouse gas emission reduction on city district scale is challenging. A single building already holds a multitude of parameters, such as building age, type or geometry attributes. A city district can consist of a plurality of heterogeneous buildings. Therefore, the number of relevant objects and their attributes rises tremendously. The city complexity can complicate data handling, which is necessary for the analysis of city districts. Thus, the data management should be simplified to support the identification of greenhouse gas emission options.

This paper describes the development of a city information model (CIM) with focus on energy systems. It accounts for different building and energy system types. The demand side is mainly represented by buildings and their user behavior. Therefore, the CIM takes building geometry, building physics as well as occupant or attendee information into account. On the generation and distribution side diverse thermal and electrical energy supply systems are included. The CIM structure has been implemented on a PostgreSQL-Server. The relational database (DB) is linked to the GIS software QGIS, which combines entity location and further object data. This enables graphical data analysis and modification. Based on a Python tool, named TEASER, building parametrization is automatized. The generated building models can be used for further analysis or dynamic simulations.

## METHODOLOGY

For the CIM as well as its implementation into a database, the following requirements are defined:

- Data management simplification (Dealing with large number of objects; GUI usage)
- Account for diverse building and energy system types (High flexibility)
- Account for data uncertainty (Simplified modeling approaches; estimation methods)
- Good interconnectability (Interfaces for data interchange)
- Enable use cases (e.g. support generation of city district models)

In the following, CIM and its related entity-relationship (ER) scheme are described. Second, the DB infrastructure is explained. Third, a Python tool for building parametrization is elucidated.

### City information model

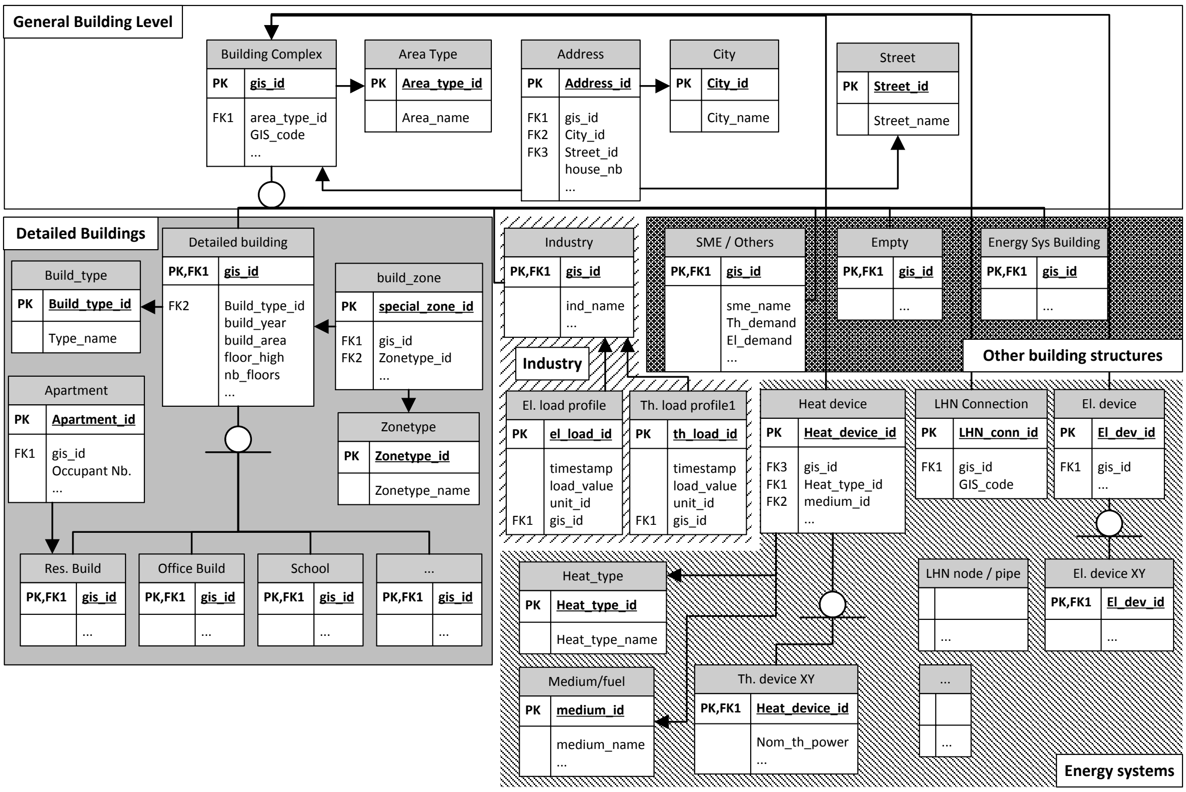


*Figure 1: Simplified Entity-relationship scheme of CIM*

The simplified version of the developed ER scheme is shown in Figure 1. The general building complex builds the scheme core. It can hold address and area type information. Furthermore, it includes a 'GIS_code', which can be interpreted as position data in a specific reference system by GIS. Possible area types are:

- Detailed buildings (with higher quality of data; comparable installed appliances and user behavior; e.g. residential or office buildings)
- Industrial buildings
- Small and medium sized enterprises or other buildings with energy demand (low level of knowledge about internal processes)
- 'Empty' area (placeholder, e.g. for buildings under construction)
- Energy system buildings (main function is energy generation; e.g. power plants)

Industrial buildings are mainly taken into account via measured load profiles. SME and other buildings with less information about internal processes are primarily modeled via estimation of annual thermal and electric energy demands, for instance, with Fraunhofer ISI statistics about specific energy demands per SME type [2].

Buildings with comparable structure or higher data quality (respectively sufficient estimation methods) are taken into account as 'detailed buildings', such as residential or office buildings. There are two main reasons for this modeling concept. First, appliance and user profiles of the same building type are comparable. Therefore, a few modeling approaches can be used to model multiple profiles. Second, necessary data, such as building ground area or building height, can be extracted from different sources, such as openStreetMap, BingMaps or CityGML datasets. If further information about internal building structure is available, special building zones can be defined. Furthermore, apartments with number of occupants are set into relation with residential buildings. Every building complex can hold a number of thermal and electric supply units as well as storage systems. Moreover, local heating network (LHN) connections are taken into account.

**Database infrastructure**

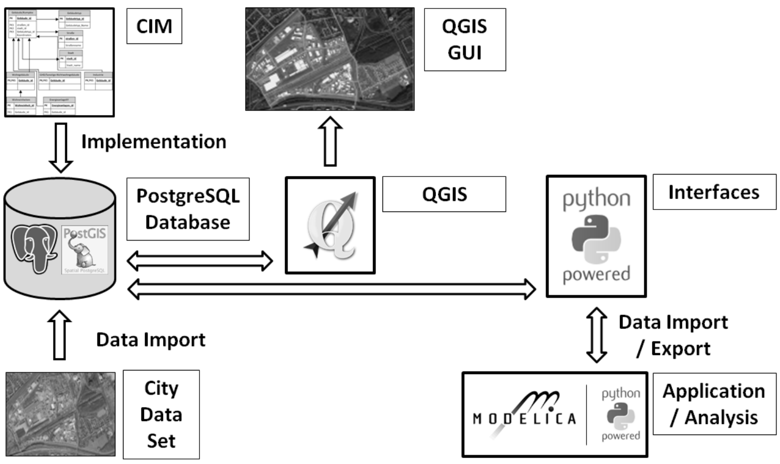


*Figure 2: Database infrastructure and interfaces*

The CIM has been implemented into a PostgreSQL database with PostGIS. The PostGIS plugin supports usage of geometrical types in PostgreSQL [3]. To simplify handling of geographical data, the open source software QGIS is connected to the database. It enables the visualization of the city district as well as modification of geographic and semantic data. Furthermore, a Python interface enables data import and export for further analysis or applications, such as dynamic simulations of city districts. Figure 2 shows the database infrastructure.

## Building parametrization tool

A possible application for the city database is the support of building model generation. Therefore, a Python tool named 'TEASER' (Tool for Energy Analysis and Simulation for Efficient Retrofit) has been developed. It is based on a Python tool originally developed by Hillebrand [4]. The tool is able to parameterize building models based on IWU building typology [5]. The modeling workflow is shown in Figure 3.

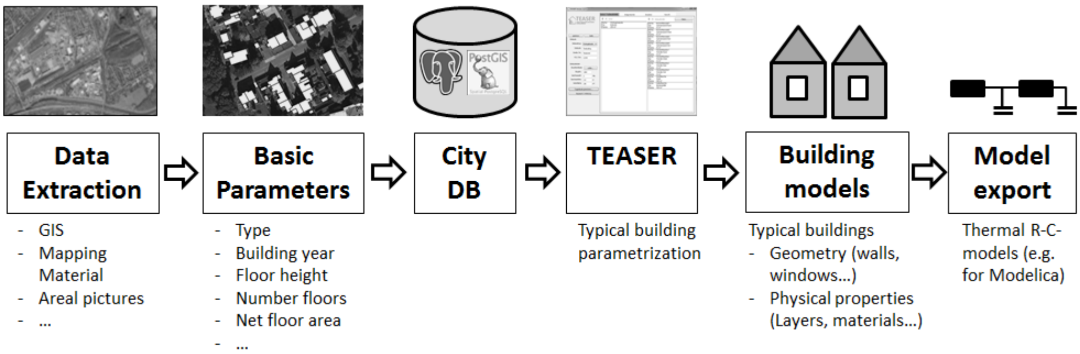


*Figure 3: Building parametrization workflow*

TEASER generates typical building geometries (outerwall, window, rooftop and basement areas) as well as typical layer structures (such as wall layers with material properties, e.g. specific heat capacity, density, heat transition coefficient and layer length), based on some elementary building parameters:

- Building type (e.g. residential)
- Year of construction
- Floor height
- Number of floors
- Net floor area

Most basic parameters can be extracted from or estimated with GIS sources or local authority datasets. TEASER can import necessary datasets via DB connection. The parameterized model sets can be saved for further modification or be exported for further usage, such as Modelica building model generation.

# CASE STUDY

A case study has been performed with an existing residential district with 248 buildings, which have mainly been constructed before 1950. The final thermal energy demand is known by statistics of local authorities. However, the state of retrofit is unknown. Therefore, the aim is to estimate the state of retrofit for the residential district. Thus, dynamic simulations within Dymola/Modelica have been performed.

## Modeling and simulation setup

DB and TEASER are used to parameterize 248 buildings of the residential district with different retrofit years (1960, 1970, 1980, 1990). To simplify the modeling of retrofited buildings, the recent retrofit year is set as building year of construction. Therefore, a retrofited building is modeled as newly constructed building within the retrofit year. This simplification might lead to wrong layer structures and parameters. However, under the assumption, that the overall heat transfer coefficient of retrofited and newly constructed buildings are comparable, due to defined building efficiency standards, the approach is valid to estimate the state of retrofiting. The buildings are exported as Modelica record files, which are used to parameterize thermal zone models of Modelica AixLib [6]. Boiler heating devices are installed in all buildings. Annual occupancy, appliance and lighting profiles are generated with a modified version of the Richardson tool [7]. The desired indoor temperature is defined as 20 °C. The test reference year (TRY) for region 5 of German weather service (DWD) is used as input for external loads [8]. Within Dymola, annual simulations are performed for the residential district with different retrofit years. The final thermal energy demand is weather adjusted with climatic factors of DWD [9], the amount of energy for domestic hot water is cleared out (64 liters per person and day with a temperature increase of 35 Kelvin [10]) and the boiler efficiency has been taken into account to generate a reference value for net thermal demand of space heating.

### Results

Figure 4 shows the normalized thermal energy demand of the city district for the different years of retrofiting (Ratio of simulated to measured space heating energy demand).

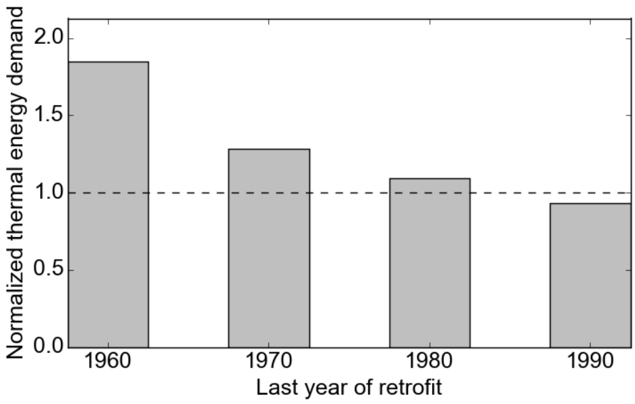


*Figure 4: Normalized thermal energy demand of city district*

The total thermal energy demand decreases regressively with higher years of retrofit, due to better building standards and shorter heating periodes. There is a good fit with an 'average' retrofit year between 1980 and 1990. Within the scope area a minority of buildings has been retrofited in 2003. Therefore, for all other buildings a reference model with mean building construction class G, respectively 1980 as last year of retrofit, is chosen (according to building class G of IWU [5]). Still, the analysis can only provide an orientation about the retrofit state. Further parameters, such as desired indoor temperature, air exchange rate or occupancy periodes, are uncertain. However, the city district DB structure and its TEASER interface enable a simplified modeling of multiple buildings and are, therefore, supportive for city district analysis.

## CONCLUSION

This paper describes the development of a city information model (CIM) with focus on energy systems. It accounts for different building and energy system types. The CIM structure has been implemented on a PostgreSQL database. The relational database is linked to the GIS tool QGIS, which combines entity location and semantic data. This enables graphical data analysis and modification. A Python tool, named TEASER, allows the automatized parametrization of building models. A database connection enables the export of necessary building data to TEASER. Within a case study, this interface is used to generate building models of a reference city district with different retrofit years. All models were simulated with Dymola/Modelica. Results show a good fit between measured thermal energy demand data and simulated thermal demand for retrofit year 1980. The usage of relational database concepts for city district data management and analysis is promising, especially in combination with GIS, which enables visualization and modification of city objects and their attributes. Though, the developed CIM scheme is not meant to be universal. Its primary goal is the simplified data handling of complex city districts. Therefore, it might not account for every possible application. Standardization on city district level will play a larger role for future applications. However, experiences show that the current CIM structure has been sufficient for the analysis of mixed city districts as well as the generation of building models for dynamic simulations.

## ACKNOWLEDGEMENTS

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