BIM SPEED

# Methods for integration of environmental and GIS data to BEM

## Deliverable 3.3

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BIM-SPEED
Harmonised Building Information Speedway for Energy-Efficient Renovation

This research project has received funding from the European Union's Programme H2020-NMBP-EEB-2018 under Grant Agreement no 820553.

# D3.3 - Methods for integration of environmental and GIS data to BEM

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## Colophon



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# Publishable executive summary

This deliverable aims at investigating the importance of geospatial surrounding and environmental data for building energy modelling. More specifically, it proposes methods for the integration of geospatial and weather data in building energy models through BIM. This report is mainly intended to provide information related to effect of these datasets in energy results for enery experts and energy modellers involved in the renovation projects.

The deliverable introduces two methodologies. The first method employs a service-oriented architecture to couple GIS (Geographic Information System) and environmental data with BIM (Building Information Modelling) to retrieve and store surrounding geospatial and environmental data. Based on this method, two services are developed and implemented as part of *D1.4: IT solutions to couple environmental, surrounding and weather data to BIM*, namely GIS data provider service and MEREEN (MEteo REelle pour la simulation ENergetique) weather service. Both services are integrated into the BIM-SPEED platform[1] and are accessible for an authorized user. Moreover, as gbXML (Green Building XML Schema) is a BIM standard enabling interoperability between building design and engineering and energy tools, a second methodology for integration of the two data schemas (CityGML and gbXML) is proposed. The proposed method aims to enrich the BIM in gbXML format with already available 3D GIS surrounding buildings data. Lastly, a description is provided about how to include surrounding data in different KPIs (Key Performance Indicator) calculation and comfort analysis. These KPIs are described extensively in *D4.1: Baseline and Use Cases for BIM-based renovation projects and KPIs for EEB renovation.*

[1] https://bimspeed.kroqi.fr

# List of acronyms and abbreviations

**ADE:** Application Domain Extension

**AEC:** Architecture, Engineering and Construction

**ASHRAE:** American Society of Heating, Refrigerating and Air-Conditioning

**BEM:** Building Energy Model

**BIM:** Building Information Model

**CS:** Coordinate System

**CRS:** Coordinate Reference System

**DF:** Daylight Factor

**DHW:** Domestic Hot Water

**EEB:** Energy Efficient Building

**EPSG:** European Petroleum Survey Group

**EPW:** EnergyPlus Weather File

**ESRI:** Environmental Systems Research Institute

**gbXML:** Green Building XML

**GIS:** Geographic Information System

**GML:** Geography Markup Language

**GPS:** Global Positioning System

**HVAV:** Heating, Ventilation and Air Conditioning

**IDF:** Input Data File

**IFC:** Industry Foundation Classes

**ISO:** International Standards Organization

**JTS:** Topology Suite: Java Topology Suite

**KPI:** Key Performance Indicator

**LOD:** Level of Detail

**MEREEN:** MEteo REelle pour la simulation Energetique (EN: MEteo REal for ENergy simulation)

**NERL:** National Renewable Energy Laboratory

**OGC:** Open Geospatial Consortium

**OSGEO:** The Open-Source Geospatial Foundation

**OSM:** OpenStreetMap

**RTSM:** Radiant Time Series Method

**SCOP:** Seasonal Coefficient of Performance

**SPF:** Seasonal Performance Factor

**TC:** Technical Committee

**TMY2:** Typical Meteorological Year 2

**TRY:** Test Reference Year

**WCS:** Web Coverage Service

**WFS:** Web Feature Service

**WMO:** World Meteorological Organization

**WMS:** Web Map Service

**WYEC2:** Weather Year for Energy Calculations 2

**XML:** eXensible Markup Language

# Contents

# List of Figures & Tables

# 1. Introduction

## 1.1 Description of the deliverable content and purpose

This deliverable aims at highlighting and analysing the importance of GIS and environmental data (climate/weather, information of the surrounding area, underground infrastructure, and energy networks) for energy modelling. Additionally, it presents methodologies for enriching BEM with such data.

Although in most renovation projects, surrounding data has not been considered in practice as an essential dataset in the data collection phase, many studies show the importance of using such data within different stages of the renovation, such as building energy modelling. Taking the environmental data into account during the renovation phase in order to have more accurate energy models is crucial. The reason is that the existing buildings reached the age of renovation accounts for 99% of the stock. Therefore, a huge opportunity to implement energy-efficient strategies comes from the renovation of existing buildings [1]. Understanding the interaction of the building with its surroundings and collecting as-built surroundings and environmental data is a pre-requisite for proposing energy-efficient renovation strategies. One of the bottlenecks of the integration of data from GIS and BIM is the scale and level of detail of data in these two domains. Despite this inconsistency, some software solutions and interoperability tools are now available to bring GIS and BIM data into one visualization platform with the possibility of both spatial and BIM analysis. The result of such integration can lead to the enrichment of the building energy modelling by combining relevant external datasets.

This deliverable, firstly, clarifies in which respect the environmental and GIS surrounding data can affect energy modelling of buildings and secondly presents methodologies for enriching building energy modelling by incorporating such data. For each of the proposed methods, practical solutions are introduced (Figure 1).

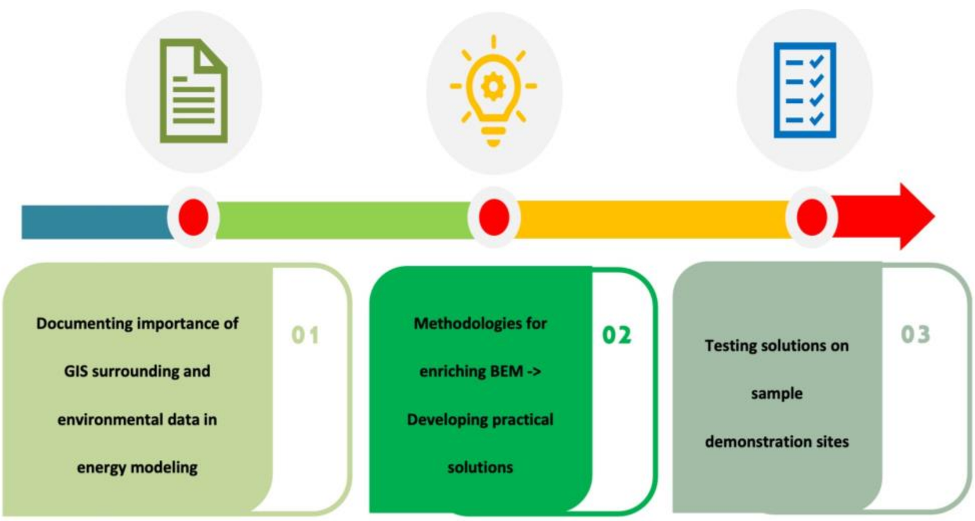


Figure 1: Main activities in T3.3 (Methods for integration of environmental and GIS data to BEM)

## 1.2 Outline of the deliverable

In Chapter 2 we start with investigating the influence of urban context on building energy modelling. For this purpose, a literature study on the importance of utilizing the surrounding data in building energy modelling was performed. Based on the findings from this review, a list of required surrounding geospatial and environmental data that can increase the accuracy of the building energy modelling is provided in the form of an ontology. In chapter 3, based on the findings in chapter 2, we propose two methodologies to enrich Building Energy Models with surrounding and environmental data. For each of the methods, practical solutions (in relation to other tasks of the BIM SPEED project) are developed. Moreover, in chapter 4 we demonstrate and implement the proposed methodologies using the developed tools on specific pilot sites of the BIM-SPEED project. Consequently, in chapter 5 we describe the relevance of GIS data for the calculation of KPIs and benchmarking developed as part of *D4.1: Baseline and Use Cases for BIM-based renovation projects and KPIs for EEB renovation*. Lastly, in chapter 6 we summarise our conclusion and propose some practical steps to enhance the implementation of these methods.

## 1.3 Contribution of partners

All the partners assigned to *T3.3: Methods for integration of environmental and GIS data to BEM* have contributed to the development of this report. More specifically, partners' contributions to the deliverable can be summerized as below.

Table 1: Partner's contribution

| # | Partner | Contribution |
|---|---|---|
| 1 | TUB | Coordinating the task as the task leader; conducting a literature review, developing the CityGML to gbXML conversion. |
| 2 | STRESS | Reviewing and commenting on the draft version of the deliverable. |
| 3 | CYPE | Documenting a report on what kind of surrounding data can be used in energy modelling of buildings in current softwares of CYPE SUITE and future possibilities . |
| 4 | UNIVPM | Documenting a report on what kind of surrounding data can be used in energy modelling of the building as well as KPI and comfort analysis of the building. |
| 5 | CARTIF | Reviewing the first version of the deliverable. |
| 6 | MTB | Documenting a report on what kind of surrounding data can be used in energy simulation of the building as well as comfort analysis of the building and performance analysis. |

## 1.4 Relation to other activities

As shown in Figure 2, *T3.3* [2]*: Methods for integration of environmental and GIS data*, which is the focus of this deliverable is related to several tasks in BIM-SPEED project. T3.3 is directly related to T3.1 and T3.2

[2] T stands for a task within the project. The full title of each task is shown in Figure 2

where the BIM to BEM conversion is presented. As an extension of the BIM to BEM conversion, BEM will be enriched with surrounding data, which can affect its accuracy. In T3.2, CYPE Suite and the BIMtoBEPS tool[3] have been utilized for the BIM to BEM conversion processes. Currently, CYPE Suite MEP uses and integrates GIS and environmental data in different stages of the energy simulation within some of its modules (Appendix 1). In addition, the solutions introduced in this deliverable help T3.4 where calibration of BEM is expected via utilizing actual long-term historical weather data provided by MEREEN weather service.

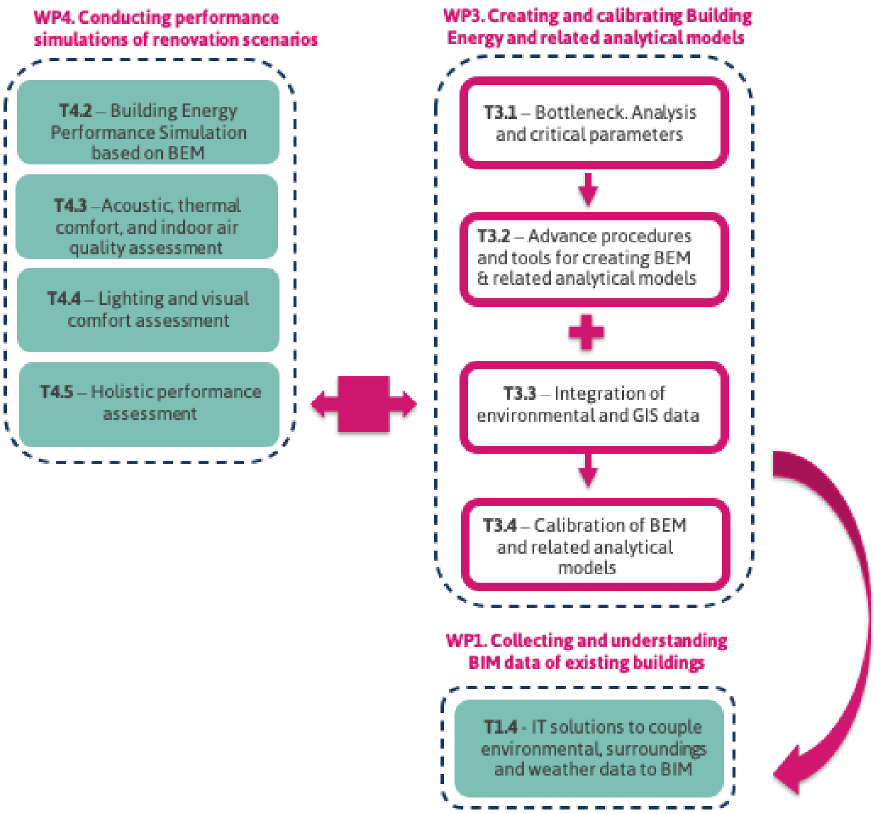


Figure 2: Relation of task 3.3 with other tasks and activities

T3.3 directly connects to T1.4, where solutions for integration of GIS and surrounding data with BIM data are introduced via the two proposed services which can be directly utilized within T3.3, as part of the practical solutions for data coupling and integration. There is also a connection with T4.2 and *WP8: Demonstrating best practices of BIM for renovation*, where several energy simulations are performed using BEM generation. The result of this work connects to T4.3 and T4.4 where comfort analysis is expected as well as T4.5 where holistic performance assessment will be done via a dashboard using the GIS data provided in this deliverable as an input. To summarise, starting from a BIM and including GIS and environmental data to obtain more accurate BEM is the main goal of this deliverable that needs to be pushed for practical use in the developments of *WP4: Conducting performance simulations of renovation scenarios tools*.

[3] BIMtoBEPS tool is developed by CARTIF

# 2. Influence of Urban Context and Environment on Building Energy Modelling

Building energy modelling for building energy efficiency is one of the use cases within the building renovation process, which is affected by the surrounding and environmental conditions of the building. Many studies focus on the effect of urban design and morphology as well as environmental conditions on the energy performance and comfort of the building. For instance, an evaluation has been carried out to understand the impact of the tree shades on buildings, and the result shows a considerable reduction in energy use in the summer season in the presence of shade casts produced by trees in the urban environment [2]. Additionally, an analysis has been performed to study the effect of exterior noise on building acoustic characteristics. Understanding the magnitude and the effect of surrounding noise are important factors, particularly in renovation projects since correct insulation of facades or replacement of windows can considerably improve indoor acoustic comfort [3]. All these studies consider urban context as a significant factor, which is ignored most of the time in practice.

Additionally, proposing an efficient and environmentally friendly technical supply of heat and reducing heat loss through a careful design of the building envelope requires a thorough understanding of the urban context while knowing what sources of energy are available in the surrounding context [4].

In particular, for energy modelling, in addition to the information related to the building and its structure, information regarding urban context, such as the building's location, climate situation of the area, shading effect of surrounding objects, orientation of the building with respect to the solar path, microclimate, and culture of consumption of the people living in the vicinity are important. Even though two buildings can have the exact physical characteristics, yet their energy demand can be different because of the urban form and context in which they are located.

## 2.1 Effective surrounding and environmental data

Surrounding geospatial and environmental data is the one that encapsulates various environmental parameters such as pollution levels, land-use change, water quality, soil quality, vegetation, public health, habitat fragmentation, etc. Although, it's not only limited to these. In general, urban context and environmental data affect building energy modelling in the following aspects [5]:

- Weather data and the microclimate
- Interaction with surrounding obstacles and shading effect
- Interaction of the building and their occupants (geo-social data)

The next chapters elaborate more on each of the aspects mentioned above.

### 2.1.1 Weather data and microclimate

The location of the building affects its environmental characteristics on different levels. The geographical condition of a city creates a specific climate condition for the buildings. Weather web services provide historical and statistical weather information from weather stations. Selecting the nearest

weather station to the building or finding the geographically optimal station can be facilitated via spatial analysis.
The historical weather data can be provided at different frequencies, namely hourly, daily, and monthly. The hourly data can provide more accurate data and is used in energy simulation engines. One of the important input parameters in building energy modelling is weather data, as it shows the exterior environmental situation of the building. Mainly three types of weather data (typical, actual, and forecast weather data) are utilized for energy simulation of the buildings depending on the purpose of energy modelling, the location of the building, and the simulation engine. The minimum weather parameters which are necessary for accurate simulation are described below:

- Dry bulb temperature
- Wet bulb temperature
- Relative humidity
- Global, direct normal and diffuse solar radiation
- Wind speed
- Wind direction

In the literature, it is emphasized that energy simulation should not be done using single year weather data, namely Test Reference Year (TRY). The reason is that a single year cannot represent the typical long-term weather pattern. Some of the long-term weather data types are:

- Actual historical long-term weather data
- Synthetic year, for instance:
    - Typical Meteorological Year 2 (TMY2) designed by National Renewable Energy Laboratory (NERL). TMY2 contains a set of meteorological data with data of months from several different years. The selection of the months is based on the monthly composite weighting of the basic data. The months that were closest to the weighted long-term distribution were selected.
    - Weather Year for Energy Calculations 2 (WYEC2) designed by the American Society of Heating, Refrigerating and Air-Conditioning Engineers (ASHRAE) [6]. The method used by ASHRAE to select data for WYEC2 was to determine for each month of the year, the single real month of the hourly data whose mean dry-bulb air temperature was closest to the average dry-bulb temperature for that month in the 30-year period of record [7].

Energy modelling of the building can be done for different purposes and use cases. One purpose can be calculating the energy consumption of the building using physics-based approaches while considering different characteristics of the geometry, HVAC systems, occupancy behaviour, and weather data. For this purpose, Typical Meteorological Year weather data are used. Considering EnergyPlus as an engine for the simulation, weather data for more than 2100 locations are available in EPW file format. This data is arranged by the World Meteorological Organization (WMO) for different regions and countries and is accessible from the EnergyPlus website. The data includes TMY2, but they are usually old datasets.
Another purpose is calculating the energy consumption of the building and calibrating the BEM with the historical data (energy bill and measures for a specific duration of time), and running new simulations to see if the difference between the simulated results and the value coming from the

bill is decreasing. In this case, long-term actual weather data, for a specific duration, can be used. In a retrofit-dominated market, accurate weather data plays a significant role in the calibration process [8].

Another purpose for energy modelling can be predicting the energy demand of a building, i.e. calculating future energy consumption. In this case, there are three options for the weather data:

- historical data, which can be long-term actual weather data,
- long-term Typical Meteorological Year weather data,
- future weather data coming from the weather forecast.

The weather stations are usually located in rural areas such as airports, which are far from the urban context. Within a city, different regions may experience diverse climate conditions because of the difference in their urban morphology. The urban context causes heat islands that can alter the weather condition from the one which is measured in the weather station located in a different urban setting. Studying the microclimate, i.e. the local set of environmental values for a specific location that differs from those in the surrounding area, can be facilitated by having access to the GIS surrounding data. Land cover, building footprint, building height, shape of the building blocks, road network, and their width can help to understand the changes in temperature and wind circulation in the urban context. Additionally, altitude, slope, land, and soil, as well as vegetation and water bodies that cause evaporative cooling, can impact in this respect as well [9].

### 2.1.2 Surrounding obstacles

The presence of the surrounding obstacles during the summer season can decrease cooling loads while reducing the thermal benefits of the sun and the natural lighting level of the internal spaces during the heating season. These obstacles can be surrounding buildings or a tree canopy, which cast shade on the reference building. Moreover, building footprints, parcel data, topographic data along with attributes related to the area, volume, height, and the number of stories of the building can provide detailed building information required to simulate the effect of the surrounding obstacles.

Besides the shading effect caused by surrounding obstacles, the urban morphology of a city can affect the energy demand of the buildings. Different studies address the relationship between energy use and urban morphology. Some of them demonstrate that higher building densities reduce energy demand, while others believe increasing density can lead to restrictions on natural ventilation and light and solar gain [10]. Other researchers believe that the densification of the city should be studied, along with the infrastructure, such as water and energy networks [11].

### 2.1.3 Population and societal data

Besides all the physical characteristics, occupants' energy consumption behaviour living in a building is one of the important factors affecting the energy demand in buildings. Having information about the population density, their age, cultural background, education, population per capita, their job, and their schedule of presence at home, which leads to the consumption pattern can give information on a higher scale about the energy demand of the buildings. Additionally, other datasets provided from location-based services such as Twitter can help to increase knowledge about the situation of an urban environment and occupants' behaviour of consumption.

## 2.2 An ontology to represent the surrounding of the building to support building energy modelling (BEM)

As part of *D1.4: IT solutions to couple environmental, surrounding and weather data to BIM,* we developed an ontology that includes entities from the surrounding and environment of a building that affects building renovation in different phases and for several use cases. One of the use cases mentioned in this deliverable is building energy modelling (BEM). Figure 3 summarizes the environmental and surrounding data connected to the exterior of the building or its environmental situation that can influence the building energy modelling. As shown in Figure 3, we categorized the geospatial data into objects and processes. Object refers to physical features such as buildings, roads, and non-physical features such as districts and boundaries. Process refers to the distribution of a specific phenomenon on the earth, for instance, the potential of solar energy in an area. This categorization aims to be at the conceptual level rather than representational model. Thus, it does not include the format of the data and the data source.

The knowledge acquisition for developing the ontology is based on literature review, investigating other relevant data schemas such as gbXML and experts' knowledge. More descriptions of the entities for each use case and the ontology itself is provided in Appendix 2. Part of the ontology which is relevant for building energy modelling is shown in Figure 3.

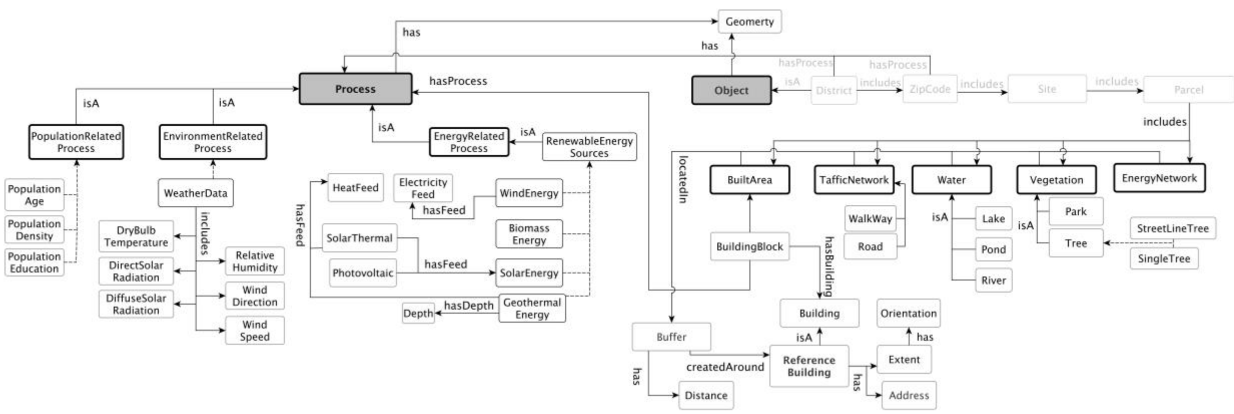


Figure 3: Surrounding geospatial and environmental data required/beneficial for BEM

The connection between this ontology and the BEM ontology introduced in *D2.2: BIM Family ontologies for materials, components, HVAC equipment in renovation projects*, is via the 'Environmental Information' component defined in the BEM ontology. The environmental information includes the object and process which represent the geospatial concepts in the ontology in this deliverable.

# 3. Methodologies to Enrich BEM with Surrounding and Environmental Data

Researchers have studied the integration of urban contextual data in building energy modelling from two perspectives; implementing energy simulation in the urban scale using GIS methods or implementing energy simulation in building scale, taking into consideration the effect of urban context concurrently [5]. The focus of the BIM-SPEED project is on building renovation at the individual building level. Therefore, accurate building energy models are required to define the optimal solution among different renovation scenarios. Given this context, geospatial data shall be used as an extra data source to increase the accuracy of energy models.

Many studies investigated the influence of surrounding obstacles and inter-building effect in energy consumption [12], [13]. [14] performed simulations in five major cities in China and studied the effect of nearby shading on electricity consumption for space cooling and heating. They demonstrated that space cooling demand decreases by 10% to 20%, while space heating demand increases by 20%. By selecting the regions from north and south, the authors also examined the effect of weather conditions in this study. [15] predicted the impact of shading on building energy loads by using a parametric method and performed more than 93000 simulations in seven cities with four thermal climate zones. They used the climate parameters and geographic location information of the cities as the input for simulation and generated a regression model to predict the shading effect. Based on their findings, cooling loads can be over-estimated by 45%, while heating loads can be under-estimated by 21%, depending on the different geographic situations. [16] quantified the shading effect of surrounding buildings and trees on the annual heating and cooling loads of buildings for four cities in Canada, representing major climate regions. Based on their findings, the heating and cooling demand of the building can change by 10% and 90%, respectively, due to the existence, orientation, distance, and height of surrounding obstructions. [17] investigated the effect of urban density considering geometry and topology in the result of energy models. [18] performed more than 1400 parametric simulations to calculate the cooling and heating demand of the buildings in Portland considering urban form. Their results show that energy consumption and density do not always relate negatively. They also believe that building energy consumption can still vary significantly with the same typology. Other studies also investigated the effect of urban form, texture, and morphology in building energy loads [12, 13].

Besides the shading effect of surrounding obstacles, another external parameter in the energy behaviour of buildings is the environmental data. Many studies explored the effect of the selection of different weather datasets considering the source, period, and type of the weather data. According to the purpose and accessibility, energy experts use different weather data types for building energy simulation, including long-term 'actual' weather data and 'typical' weather data [19]. Historical 'actual' weather data represents the real values of different weather parameters for a location. On the other hand, 'typical' weather data represent a typical long-term weather condition. Most previous studies compared the results of energy simulation from a 30-year period 'actual' weather data (real historical weather data) and 'typical' weather datasets including TRY, TMY, TMY2, WYEC, and WYEC2 fordifferent locations [6], [20], [21]. Some of them are focused on studying peak demand due to using different weather datasets [22]. Among them, [6] shows variation between -11% to 7.0%, while [23] for ten different locations in the US shows a maximum of 5% variation. [24] for a building in Greece show a reduction of the heating energy by 11.5%, while [25] show an increase in energy use between 5%-9% depending on the characteristics of the building. More general conclusions present that TMY3 simulation results can be significantly higher or lower than those of the 'actual' weather datasets [22].

In studying the 3D data integration to support energy modelling of buildings, some studies emphasize the importance of data transformation from CityGML to gbXML to use already available geospatial datasets in CityGML format [26]. In this deliverable, we argue that in addition to the transformation of CityGML to gbXML, the integration of these two data models can be helpful.

In previous studies, there are three gaps which we try to address in this deliverable. Firstly the service-oriented approach is not applied extensively to extract 2D geospatial datasets to support building energy modelling. Therefore, in this deliverable we propose a service-oriented architecture for coupling 2D surrounding geospatial and weather data with a building model. We argue that it is also possible to get the advantage of the 2D GIS data and use it for specific applications in building renovation and building energy modelling. In this case, a minimal design for software architecture is required, while the provided geospatial data can still be helpful for specific tasks.

Secondly, studies focused on investigating the effect of weather data, did not investigate recent actual weather datasests in comparison to typical weather data. In this deliverable, we propose a weather service solution which provides actual weather data from 2005 to 2020, which is very recent. This datasets for any location of interest provides the possibility for investigating the effect of climate change in energy efficiency of buildings.

Lastly, as mentioned a method for integration of 3D surrounding buildings in CityGML format into gbXML model of the building is missing. We introduce a customized methodology for integrating surrounding geospatial datasets in CityGML format into the building in gbXML data schema to consider the surrounding buildings directly in the BEM of th building.

## 3.1 Enriching BEM with surrounding and environmental data through coupling between geospatial data and BIM by employing service-oriented architecture (SOA)

Integration can be done at different levels: data-level, process-level, and application-level [27]. Integration at the process level does not change the data format and structure of both sides. One of the methods in this level is web-based service-oriented methods. [28] developed a service-based 3D model solution that integrates CAD/BIM and GIS data and generates a virtual 3D City Model. In their research, they used several OGC web service types. They demonstrate that it is simpler to use services to integrate the data from different scales, domains shareholders seamlessly. In another study, [29] linked BIM and GIS in a District Information Modelling Management for energy reduction. They used a web-service oriented open platform, which processes and visualizes the real-time district-level data. In this research, they improved the interoperability issues by developing a common platform where different databases can share information.[30] employed a service-oriented architecture to connect the components of BIM and BEM for information synchronization and collaboration. They believe using the SOA approach helped to simplify the data exchange between BIM and BEM. [31] leveraged existing standards such as IFC and WFS and discussed the challenges of defining a web service for serving building information. By experimenting, they proved the feasibility of merging CAD, GIS and BIM data obtained from web services.

As suggested by these studies, service-oriented approach is an efficient method for coupling data from different domains. Accordingly, in our first proposed methodology, we employ a service-oriented architecture (SOA) to couple BIM and GIS data. The goal is to retrieve and store 2-dimensional geospatial and weather data. We utilize the first level of data coupling (one-way data transfer) for data integration in this research. On this level, data shall be transferred from Model A to Model B (Figure 4) while the models remain separated. In this context, coupling means that one model (or parameters of one model) is the input for another model [32]. One of the advantages of using this approach is the reduced initial cost due to minimal design [32].

Based on Figure 4, if Model A is the BIM of the building (in IFC format), the main parameter from this model is the exact GPS location of the building. Nevertheless, the IFC file should include the location of the building. Based on this input, the coupling results to Model B. Model B is the weather data and the surrounding geospatial datasets related to the building.

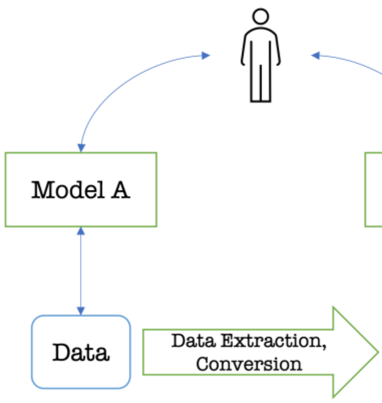


Figure 4: Data Coupling; first level: one-way data transfer

Two services are implemented based on this methodology, namely MEREEN weather service and BIM-SPEED GIS data provider service. As shown in Figure 5 (step 1), both services use IFC files as input (to extract the exact GPS location of the building). Then each service is connected to the sources of data to extract the relevant surrounding data. The retrieved data is then accessible through the BIM-SPEED platform, and it is also possible to locally download it to visualize it in a GIS software. This method helps in retrieving geospatial and weather data for specific buildings according to their exact GPS location. One service retrieves the geospatial data at a certain distance around the building, and the other service collects weather data from the closest weather station. Therefore, the basis for data retrieving and selection strategy is geoprocessing.

The MEREEN service collects weather data from NOAA and Copernicus archives. The GIS data provider service extracts the geospatial data from WFS (Web Feature Service) registries provided by the authorities and municipalities for a city. The availability of data is dependent on the municipalities of cities.

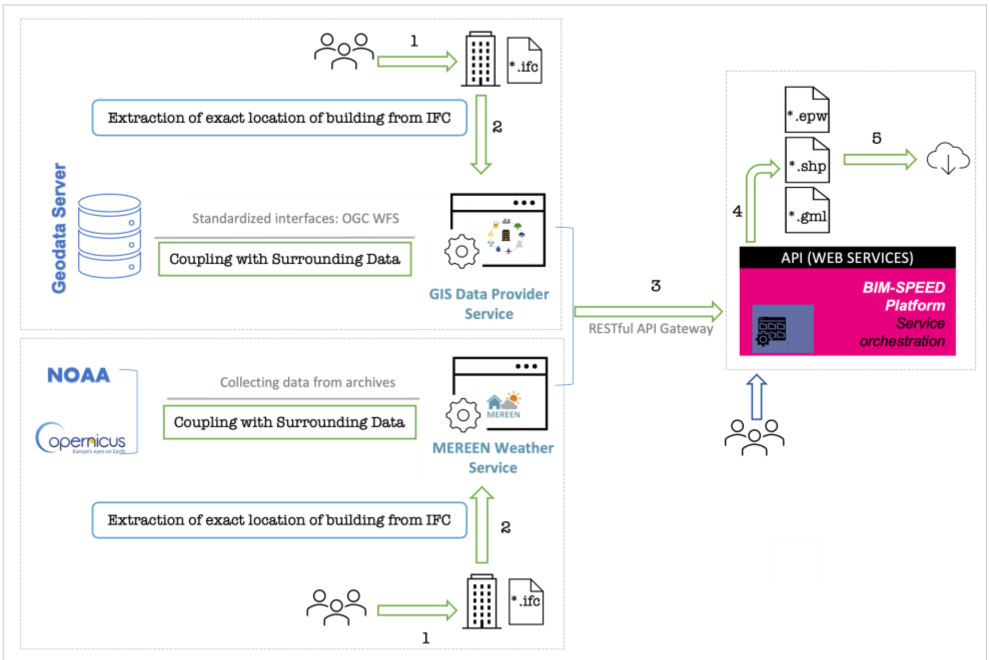

Figure 5: Software architecture of the two services implemented according to the first methodology

## 3.1.1 MEREEN weather service

MEREEN weather service is implemented to collect long-term recent actual historical weather data from the closest station to the demonstration sites. The connection with the BIM data is through the extraction of the GPS location of the demonstration site from the IFC file.

The recent actual weather data can be used for calibration purposes. In addition, generating the 'typical' weather data from more recent long-term data is expected in the next versions of the service. The up-to-datedness of weather data increases the accuracy of energy simulation. From the user perspective, the service works as shown in Figure 6.

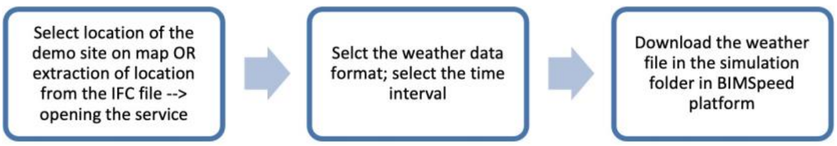

Figure 6: Workflow of selecting the most appropriate weather file

The first step is the selection of the building and retrieving the location. The service performs this by extracting it from the IFC file of the building. Subsequently, the service selects the nearest station via geoprocessing and performs a data quality analysis on the outcome. The result is an EPW file that can be used in the EnergyPlus engine for energy simulation. The method for enriching BEM with weather data is through the coupling of BIM and weather data. The result of the coupling can be used directly in BEM.

## 3.1.2 BIM-SPEED GIS data provider service

As already mentioned, surrounding objects such as buildings, vegetation, roads, and so on, as well as processes such as energy network and consumption and distribution of renewable sources of energy in a district, can have a significant impact on building energy modelling. Renewable sources of energy can make electricity without producing $CO_2$ which is the major cause of global climate change. Buildings account for 40% of total energy consumption in the EU [33], and as solutions in the EU Directive for building renovation, reduction of energy consumption and use of energy from renewable sources is considered as an important measure [34].

BIM-SPEED GIS data provider service implemented as part of the *D1.4: IT solutions to couple environmental, surrounding, and weather data to BIM* of BIM-SPEED project, helps retrieve and store these datasets for different use cases and a specific demonstration site. This service does not propose any approach for directly integrating these geospatial datasets into BEM but provides access for the user to the surrounding energy-related data that certainly can help in the decision-making, comfort and performance analysis, and energy modelling of the building.

The connection with the BIM data is through the extraction of the GPS location of the demonstration site from the IFC file. The result of GIS data provider service is 2D vector data (the next versions shall retrieve maps and raster data as well) in GML and Shapefile formats, which can be visualized in GIS software applications and used for different purposes.

WFS registry links of the geospatial features published by authorities and organizations have been used to access these datasets (Figure 5). More technical description of this service and how to access it is available in *D1.4: IT solutions to couple environmental, surrounding and weather data to BIM*.

Same as the MEREEN weather service, the enriching method is the coupling of BIM and GIS data. The extracted datasets provide accurate knowledge about the surroundings, such as energy networks, renewable sources of energy, surrounding buildings, and roads. Further analyses are required for shading effect and microclimate analysis, which are beyond the scope of this deliverable.

## 3.2 Enriching BEM by including surrounding buildings via transforming CityGML (surrounding 3D geospatial data) to gbXML

CityGML is the most popular 3D GIS open data model which is used by municipalities to represent city objects. CityGML is XML-based and is an application schema of OGC GML (Geography Markup Language) which is used to represent geographical features [35]. CityGML neither includes information regarding the energy of the building nor is an acceptable format in building energy simulation soft-wares [36]. Although, it has a mechanism called CityGML ADE (Application Domain Extension), which extends the concepts in CityGML to those relevant to a new use case. [21] used this approach and developed a CityGML ADE for energy by data transformation between gbXML and CityGML [37]. The building energy model in gbXML format is used to extract energy data which is then integrated into the CityGML data model and is also used to formulate the semantics and conceptual schema in CityGML energy ADE.

In the construction domain, besides IFC that is the most popular standard, gbXML is used as an XML-based data schema to facilitate the transfer of building data from BIM to energy and engineering analysis tools. It includes the 3D geometry of the building and the information required for energy simulation.

Integrating 3D geospatial data with BIM turned to the centre of attention recently. This integration is usually done via IFC and CityGML transformation as the two most popular formats in BIM and GIS [38], [39], while as [26] mentions, significant time can be saved by transforming 3D objects from CityGML to gbXML utilising the transformed geometry for energy simulation. [36] used an Extensible Stylesheet Language Transformation (XSLT) and assigned the boundary surfaces of the building in CityGML to the surfaces in gbXML. IFCExplorer implemented in KIT has some possibilities to integrate CityGML and gbXML in one environment [40]. Most of these studies suggest converting CityGML to gbXML to provide the geometrical information for gbXML from CityGML. In this research, we aim at enriching BEM (gbXML) with CityGML data by transforming CityGML to gbXML to add surrounding buildings to the gbXML.

Therefore, as a result, our customized transformation methodology includes the building (originally in gbXML format) and its surrounding buildings (originally in CityGML format) in gbXML format. With this, we aim at enriching BEM with surrounding buildings as they affect the energy modelling via the shading effect. As mentioned, an effective parameter in building energy modelling is the shading of surrounding buildings. Having 3D data of the surrounding buildings or building footprints along with information related to its height and façade texture can help in this respect. The shading effect of the surrounding obstacles can alter the result of the building energy modelling. Also, it has an impact on the thermal and lighting comfort of the building. Today, municipalities provide 3D GIS data of the buildings in the cities in CityGML data format. Integration of these already available 3D datasets in BIM data can help enrich the BEM and increase the accuracy of different analyses, particularly in the renovation workflow. To this end, we propose a customized methodology for the transformation of CityGML data to gbXML format.

The gbXML and CityGML have differences in semantics and definitions, but they are both based on XML that makes them easy to understand. More description of the gbXML data schema and the CityGML data model is provided in Appendix 3.

### 3.2.1 Integration method

The gbXML and CityGML data schemas use different semantics to define the same objects on the earth. CityGML has a modular structure that includes building city furniture, water bodies, vegetation and more, while gbXML is covering mainly detailed information of a building required for energy simulation. Another difference between CityGML and AEC domain standards such as IFC and gbXML is that the former was intended primarily to allow the description of the urban environment as it is, while the latter was intended for designing a building [41]. The design of built facilities in the AEC domain is performed in the Cartesian Coordinate System (CS) with an arbitrarily chosen project base point, which is the result of the projection of the curved world onto a plane. The geospatial domain, on the other hand, is based on Geodetic Coordinate Reference System (CRS) to consider the curve of the earth accounting for data on a higher scale. When coordinate systems are different, a transformation is required to bring data from one system to another.

Some other differences are that gbXML despite CityGML has a lack of semantic information, multi-scale representation, geospatial reference and, ADE (Application Domain Extension) mechanism to extend the model for new applications [42].

Despite this incompatibility, there are some similarities between gbXML and CityGML. These similarities can be used as a basis for a solution to transfer data from one to another. One is that both data schemas are XML-based, which is easily readable and understandable. Another characteristic of both is the presentation of the building's geometry based on the surface. Boundaries such as a wall, roof are defined by surfaces.

A proposal in this deliverable is to bring the already available CityGML data of a reference building and its surrounding to the gbXML file via data schema conversion. In the following, we provide a detailed explanation of the challenges and the workflow for integrating CityGML data with gbXML. Figure 7 represents surfaces in gbXML and CityGML data. The goal in this study is to transform the surfaces in CityGML, namely the *WallSurface*, *RoofSurface*, and *GroundSurface* (CityGML LOD2) to *Shade* surfaces in the gbXML data schema. As can be seen, all surfaces of the surrounding buildings are assigned to shade surface type, while in CityGML, it is possible to distinguish the components of a building.

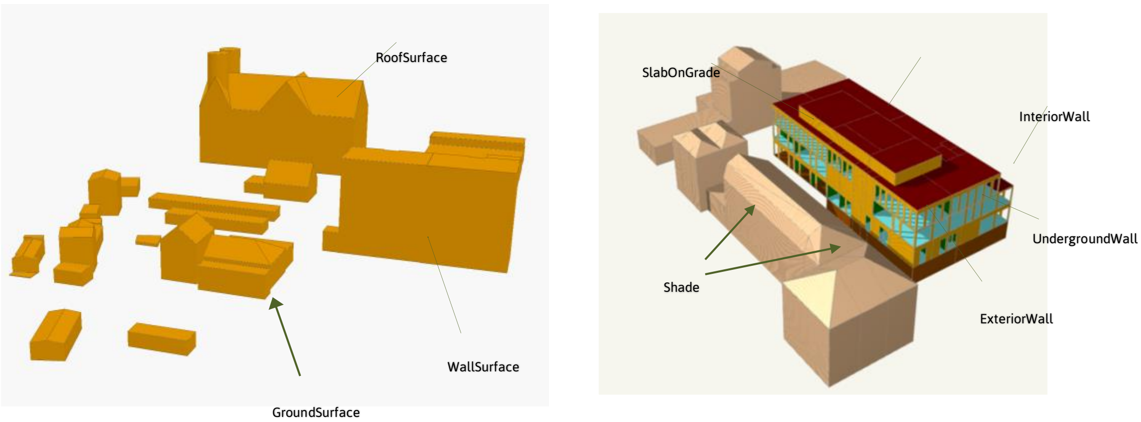


Figure 7: gbXML data and its surfaces VS. CityGML data LOD2 and its surfaces

As explained above, the Coordinate Reference Systems (CRS) used for CityGML and gbXML differ from each other, so a transformation is required. To transform the coordinates, access to the XML files of both models is required. As shown in Figure 8, a surface in the gbXML file contains a '*Polyloop*' including some cartesian points. Each point includes three coordinates namely X, Y, and Z. Each surface in CityGML is also defined by a polygon consisting of a list of coordinates in the *'posList'* tag. A transformation is required to convert coordinates in the global coordinate system to a local coordinate system in which the gbXML file is defined.

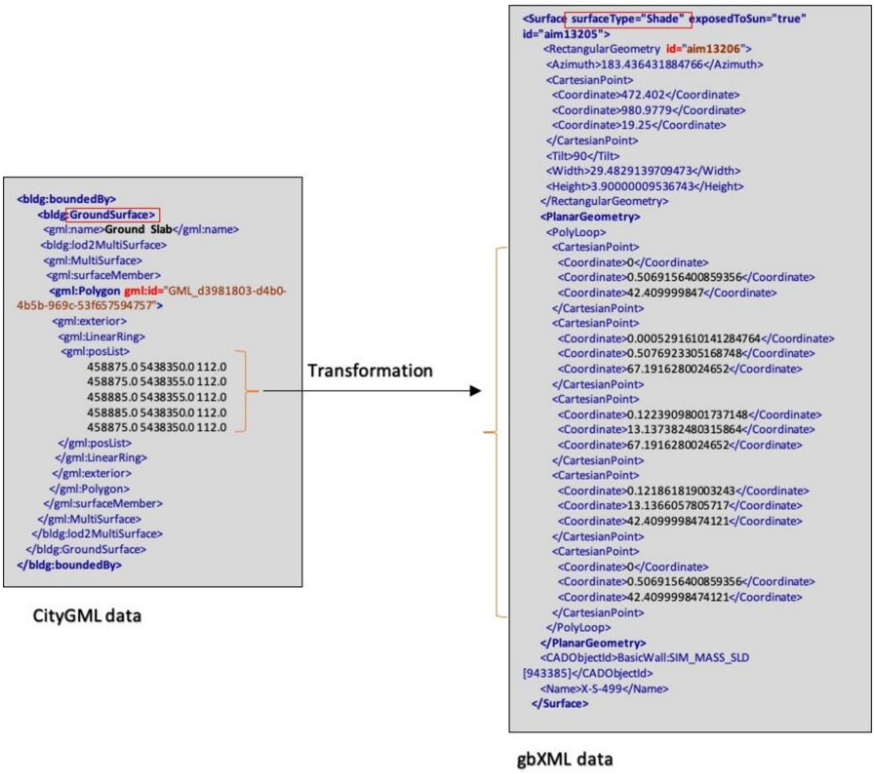


Figure 8: The gbXML and CityGML XML files

To find the transformation strategy, two reference points from the data and a transformation matrix to consider the rotation is required. The equation below shows the rotation matrix. The justification for this definition comes from Figure 9 [43].

$$R(\theta) = \begin{pmatrix} \cos\theta & -\sin\theta \\ \sin\theta & \cos\theta \end{pmatrix}$$

$$L(E^1) = (cos\theta)E^1 + (sin\theta)E^2$$

$$L(E^2) = (-sin\theta)E^1 + (cos\theta)E^2$$

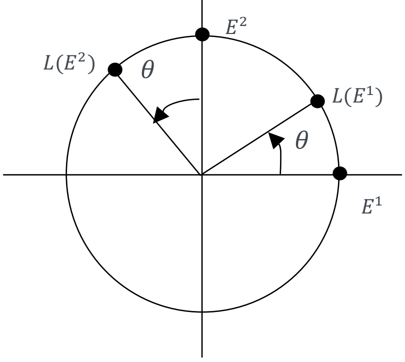


Figure 9: Justification for rotation matrix

The workflow in Figure 10 shows the procedure to transform coordinates of ground, wall, and roof surfaces of the building in CityGML LOD2 to the gbXML shade surface. This methodology is used to develop a python script, which uses the CityGML and gbXML file as input and provides a gbXML file as output including the surrounding data. In the following, a description of the workflow is presented.

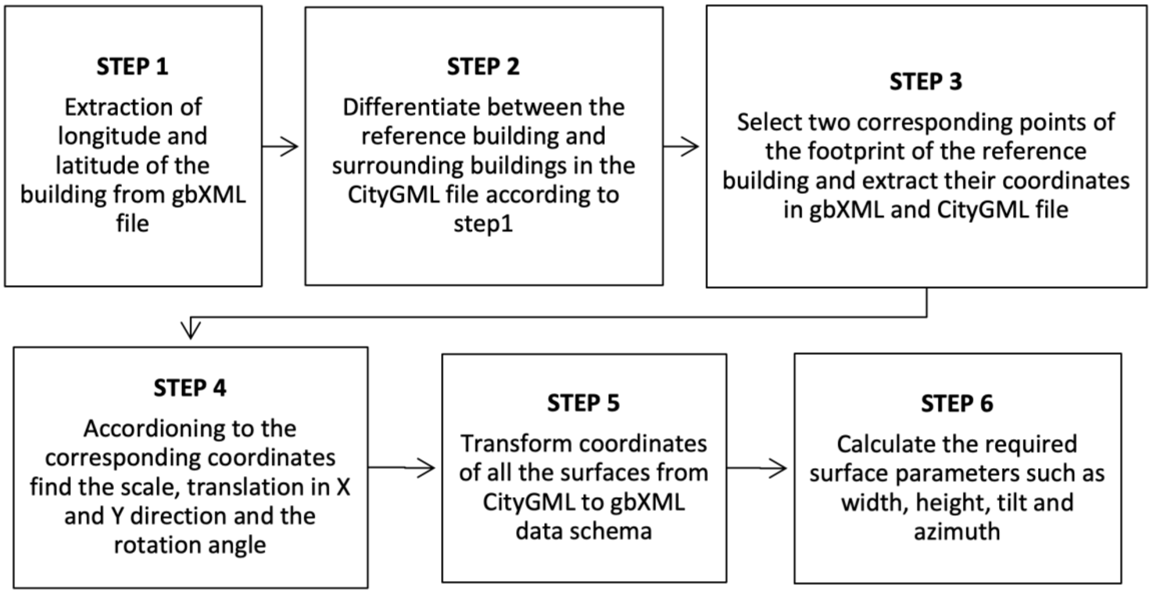


Figure 10: Workflow of transforming CityGML surface to gbXML surface

**Step 1: Extraction of longitude and latitude of the building from gbXML file**

The gbXML file contains information regarding the location (longitude and latitude) of the reference building. This location is usually not very accurate and is the location of the street where the building is located. As this location is utilized as the reference for data conversion, it is mandatory to have this location very accurate. If this location is not precise, a pre-processing is required to update the gbXML file, or assign the reference longitude and latitude manually.

**Step 2: Differentiate between the reference building and surrounding buildings in the CityGML file according to step 1**

The next step is to differentiate between the reference building and surrounding buildings in the CityGML file. The result of the first step is the longitude and latitude of the reference building, while CityGML file may use another reference system to show the coordinates. The EPSG code is a standard code for coordinate systems, datums, spheroids, and units. To find out the correct location of a feature in the real-world, it is required to know that in which EPSG its coordinates are defined. The EPSG code of a CityGML file is provided in the '*Envelope*' tag. To find the reference building in the CityGML file these steps are required:

- Create polygons based on the vertexes of the *GroundSurface* from CityGML file.
- Transform the reference longitude and latitude (from gbXML) to the EPSG code of the CityGML file.
- Using geoprocessing tools, check in which polygon the reference point is located.
- Select the *id* of the *GroundSurface* as the id of the reference building.

- For selecting surrounding buildings, a buffer can be generated around the reference building to select only those buildings in a specific radius. There are different geoprocessing libraries available, for instance, JTS Topology Suite (Java Topology Suite) and GeoTools, that are supported by OSGEO (Open-Source Geospatial Foundation).
- Assign the rest of the surfaces as surrounding buildings.

**Step 3: Select two corresponding points of the footprint of the reference building and extract their coordinates in gbXML and CityGML file**

To find out the transformation strategy, selecting two corresponding points of the reference building footprint from the gbXML file and CityGML file and extracting their coordinates are required. This step has been done currently manually in the script, but it can be implemented via a graphical user interface where the user can select the points on a map.

**Step 4: Accordioning to the corresponding coordinates find the scale, translation in X and Y direction and the rotation angle**

The coordinates from the previous step can be used to find the scale, translation in X and Y direction and the rotation angle. Considering the coordinates of the two points in CityGML as (X1, Y1) and (X2, Y2) and their corresponding coordinates in gbXML file as (x1, y1) and (x2, y2), the rotation angle can be calculated as shown in equation below:

$$\theta = \tan^{-1}\frac{X1 - X2}{Y1 - Y2} - \tan^{-1}\frac{x1 - x2}{y1 - y2}$$

The translation in X and Y direction are as: $\Delta X = X1 - x1;\ \Delta Y = Y1 - y1;$

And the scale shall be calculated as: $S = \sqrt{}((x2 - x1)^\wedge 2 + (y2 - y1)^\wedge 2)/\sqrt{}((X2 - X1)^\wedge 2 + (Y2 - Y1)^\wedge 2)$

**Step 5: Transform coordinates of all the surfaces from CityGML to gbXML data schema**

According to the parameters calculated in the previous step all surfaces can be transformed now from CityGML to gbXML according to the equation below:

$$\begin{pmatrix} X \\ Y \end{pmatrix} = S\begin{pmatrix} \cos\theta & -sin\theta \\ sin\theta & cos\theta \end{pmatrix}\begin{pmatrix} x \\ y \end{pmatrix} + \begin{pmatrix} \Delta x \\ \Delta y \end{pmatrix}$$

The transformed surface needs to be assigned as '*Shade*' surfaceType. This can be done by generating new tags in the gbXML file.

**Step 6: Calculate the required surface parameters such as width, height, tilt, and azimuth**

Next step is calculation of width, height, azimuth, and tilt parameters of the surfaces. Among these parameters, width and height can be simply calculated from the coordinates. Azimuth is the angle between the north and the normal vector of the plane, and the normal vector can be generated from two vectors of the plane which are created from 3 points of the surface. The tilt of a surface is the angle between the surface and the horizontal surface. This angle can be calculated from the angle between the normal vectors of the reference surface and horizontal surface (Z=0) (Figure 11).

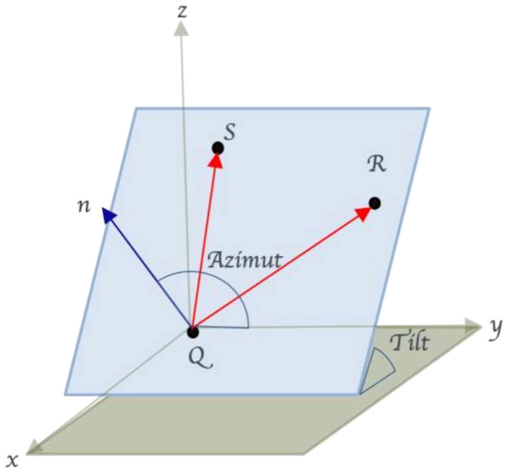


Figure 11: Azimuth and tilt in definition of surface in gbXML data

# 4. Demonstration

This section demonstrates how each of the methodologies mentioned in the previous section can enrich BEM with surrounding and environmental data. The quantification of the effect of surrounding data integration in BEM is only possible on a case-by-case basis, as every building and its context will vary. We will provide detailed quantifications around the demonstration cases in later deliverables. Potential/Planned analysis includes performing sensitivity analysis on the energy consumption of buildings due to different weather formats, sources, and periods and surrounding obstacles to study the shading effect.

## 4.1 Service-oriented architecture to collect environmental and surrounding data

### 4.1.1 MEREEN weather Service

Figure 12 shows how to access the weather service from the IFC file from the BIM-SPEED platform. After opening the service, a pop-up will open which shows the name of the nearest weather station, along with the data provided for that station for different time intervals and from different sources (Figure 13). Within this pop-up it is possible to select the period and the data format (Figure 14). the result will be downloaded in the relevant folder in the BIM-SPEED platform. MEREEN weather service is available online via this link as well: https://mereen.dimn-cstb.fr/map/fr[4]

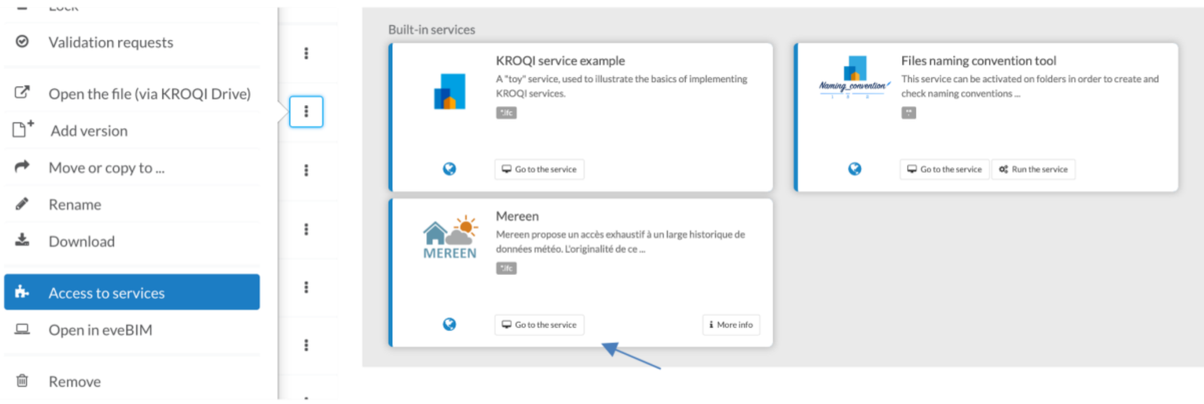


Figure 12: Accessing weather service from IFC fileAccessing weather service from IFC file

[4] The service is only available through authentication.

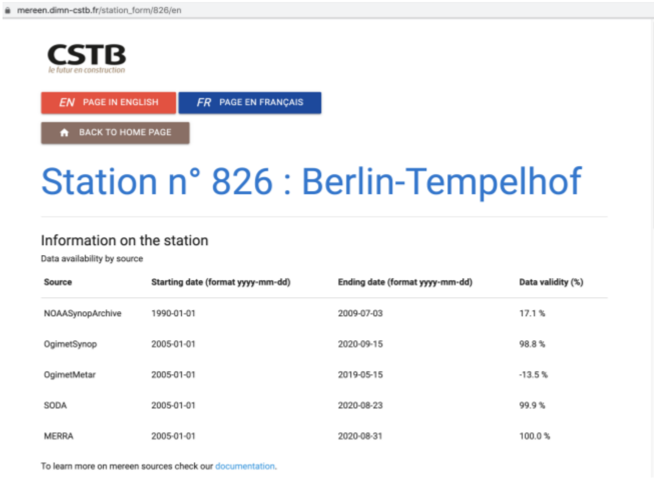

Figure 13: Information about selected station

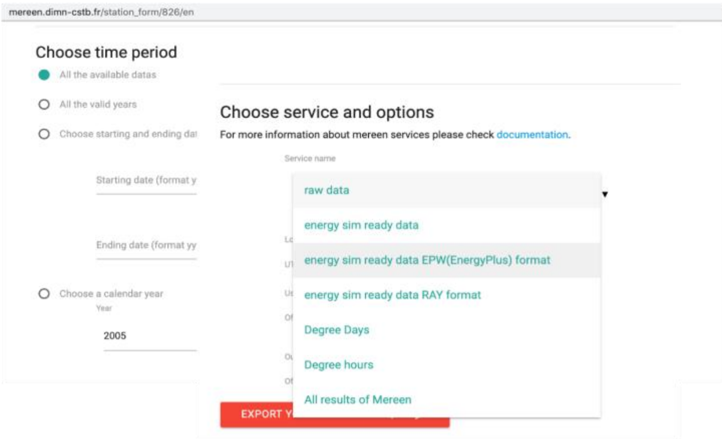

Figure 14: Selection of period and weather data format

Nearest weather station to the Berlin demonstration site and a snapshot of the collected data, and a map of all stations is shown in Figure 15 and Figure 16 respectively. The retrieved data is actual weather data, so it can be used for calibration purposes. Also, it is possible to use it to study how accurate other weather formats such as TMY are.

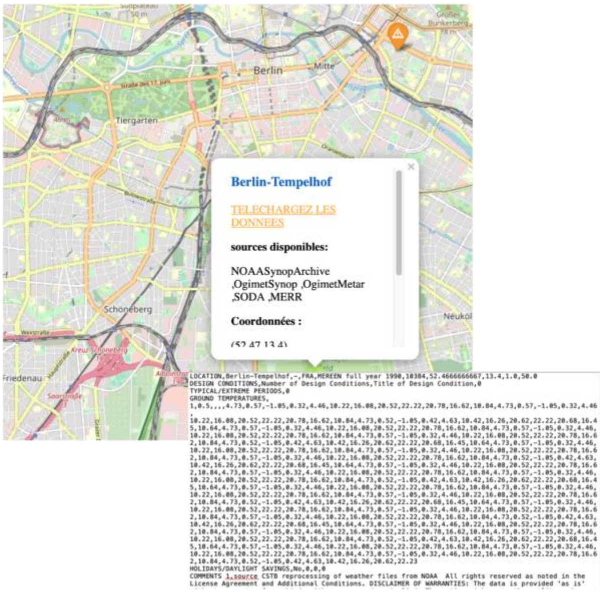


Figure 15: Closet station to Berlin-Lichtenrade demo site and collected data

Figure 16: Map of all the weather stations in MEREEN weather service

### 4.1.2 GIS Data Provider Service

Figure 17 shows how to access the GIS data provider service from the IFC file from the BIM-SPEED platform. After opening the service, the wizard shows a list of use cases one of which is building energy modelling (Figure 18). Selecting each use case suggests a list of surrounding geospatial data which can be useful for that use case. Following the next steps ends to storing the data in Shapefile or GML format in the BIM-SPEED platform and subsequently locally downloading. The downloaded geospatial datasets are visualized in ArcGIS version 10, and their maps are generated.

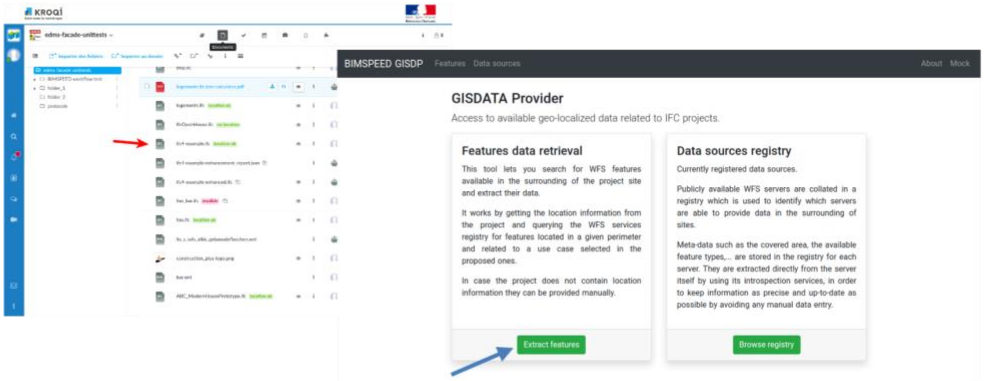

Figure 17: Accessing GIS data provider service from BIM-SPEED platform and IFC file

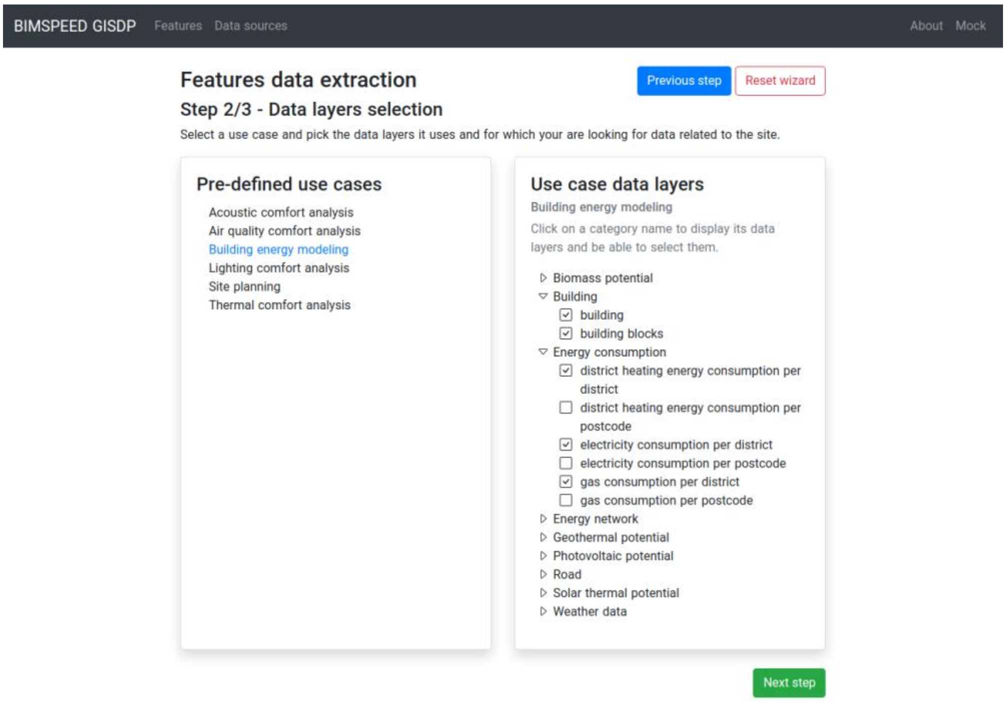

Figure 18: Required surrounding data for building energy modelling

For demonstration, we visualized renewable sources of energy on maps. We assume they are critical data layers at the district level. This data can influence the decision-making in renovation workflow and can affect the energy modelling of buildings. Within principal challenges of renovation technologies, renewable sources of energy have been ranked in the second level of impact after the insulation, although the cost of renovation remains high [44]. Figure 19 shows some of these data layers related to renewable sources of energy for the city of Berlin.

One of the principal information in building energy modelling as input is the energy source of the building. It can include gas, oil, and district heating. Alternative options are renewable sources of energy such as solar energy, wind, biomass. For energy modelling of a building, the energy expert requires this information. If it is not available, the energy expert assumes based on rough available information. Information about these energy sources and their potential in the district or zip code level can reveal some knowledge about the building. For instance, if the maps show that the building is in a district with high biomass potential rather than wind potential, the experts can focus on those sources and use them in the model. Energy modelling is one of the inputs for designing different scenarios for energy-efficient building renovation. Energy experts can use accurate information provided by municipalities at the district level in case of a lack of data at the building level.

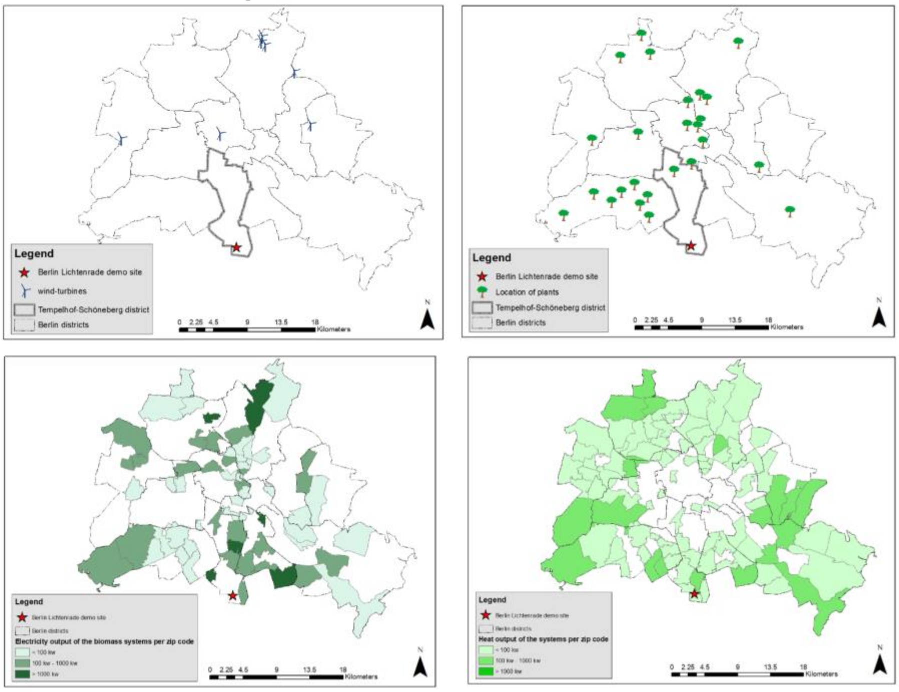


Figure 19: Renewable energy potential in Berlin city

Participation and connectedness of different components of the city and open access to data are required to move toward a smart city. Smart grids as electricity grids work as a connected operating system that is used for the energy transition. Today, renewable sources of energy, such as wind turbines and solar cells, can generate a large amount of energy. This energy supply needs to be distributed to the areas where it is required by using smart grids. The intelligence in the smart grid provides reliability to respond quickly to feed and consumption in the regions. Although BIM-SPEED GIS data provider service in this deliverable does not provide data regarding the smart grid, there are some services already available from organizations that provide such data for different cities. Appendix 4 provides an example of how to access the smart grid data.

## 4.2 Integration of CityGML data with gbXML data

The methodology described in the method section is used to write a script in Python[5]. The gbXML file of one of the BIM-SPEED demonstration sites in Gdynia, Poland, along with the transformed ground surfaces (the footprints of surrounding buildings) is shown in Figure 20. An online gbXML viewer has been used to view the gbXML file after the conversion. The same approach can be done for the integration of all surfaces of the 3D data in CityGML format LOD2 (i.e. *GroundSurface*, *WallSurface,* and *RoofSurface*).

[5] The script is not publicly available.

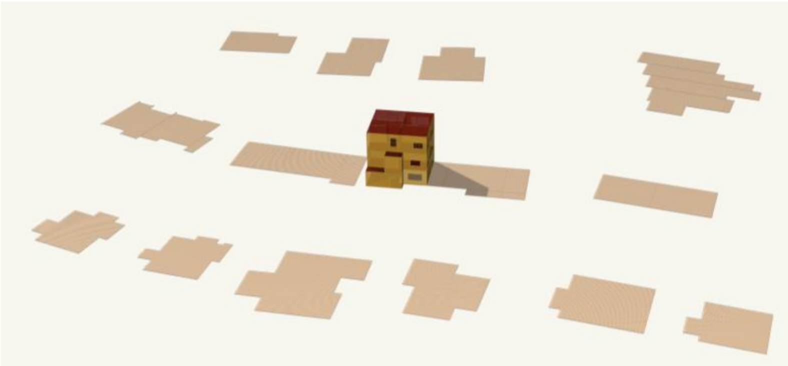

Figure 20: Integration of footprints of the surrounding buildings with gbXML data

# 5. Relevant contribution of GIS data for calculating KPIs and benchmarking

One of the goals of the BIM-SPEED project is to reduce environmental and societal impact. BIM-SPEED is expected to affect energy saving and $CO_2$ emission reduction by 60% through deep renovation. This effect is calculated via a set of KPIs (Key Performance Indicators) that are verified in different EU EEB projects. KPIs are defined in three different categories, namely environment, society, and economy, and are used for the assessment of the sustainability of building renovation. Defining different scenarios for renovation and assessing the performance before and after renovation requires making use of both measured and simulated data.

Each of the KPIs comprises a formula that requires a set of input data. The input data may be relevant to the building or the exterior situation of the building. The relevant exterior data can be either environmental factors such as weather data or geospatial objects and processes such as renewable sources of energy, primary energy, and final energy value in a country and so on. This section focuses on the contribution of GIS surrounding and environmental data that can help to increase the accuracy of the KPI calculation. Some of the KPIs which are affected by exterior data are listed below:

- Operational primary energy demand
- Total energy demand
- Total energy consumption
- Energy signature
- Global warming potential
- Thermal comfort
- Acoustic comfort
- Visual comfort
- Indoor air quality

A detailed description of each of these KPIs and the input required for them are available in *D4.1: Baseline and Use Cases for BIM-based renovation projects and KPIs for EEB renovation.* One of the essential datasets as input for some of these KPIs is the primary and final energy for different energy carriers. European and national organizations such as Eurostat[6] has provided some related data, but the result is very scattered. Within the European Commission, there was a study in 2012 about Mapping and analyses of the current and future (2020 - 2030) heating/cooling fuel deployment (fossil/renewables). Within this study, some information regarding the final energy for different carriers in different countries of Europe is provided [45]. In addition to the information related to energy in different countries, external weather data (particularly actual weather data) is required. MEREEN weather service developed as part of *D1.4: IT solutions to*

[6] https://ec.europa.eu/eurostat

*couple environmental, surrounding and weather data to BIM* can provide recent historical weather data for different demonstration sites.

For acoustic and air quality comfort analysis, there is a need for outdoor information regarding noise and pollution. Lighting and visual comfort analysis of the building is affected by the surrounding obstacles. Moreover, decision making regarding different renovation scenarios requires information about the available renewable sources of energy in the district. BIM-SPEED GIS data provider service developed as part of *D1.4: IT solutions to couple environmental, surrounding, and weather data to BIM*, provides most of these data in geospatial data formats that can be visualized on maps using different GIS software applications.

# 6. Conclusions and future works

This deliverable aims at pointing out the significance of the surrounding and environmental conditions in the energy analysis of the buildings. Different interactions of the building with its surroundings have been discussed and following those two methodologies are suggested to integrate GIS and environmental data with BEM.

As part of the first methodology that employs service-oriented architecture, the deliverable introduces two solutions. One solution is to access the weather data as one of the essential inputs for energy simulation. The MEREEN weather service has been developed and is integrated into the BIM-SPEED platform and is available for authorized users. Users can download long-term recent 'actual' weather data in EPW file format in the BIM-SPEED platform and use it for simulation. The BIM-SPEED project can benefit from this tool, particularly as part of *T4.2: Building energy performance simulation based on BEM* and *WP8: Demonstrating best practices of BIM for renovation*, for performing building energy modelling and building energy performance based on BEM. Future versions of this service will include 'typical' weather data generated from more recent datasets. Also, forecasting weather data considering the climate change effect is another future research topic.

Moreover, to find out about renewable sources of energy, energy network in the area, and many other geospatial datasets, the BIM-SPEED GIS data provider service has been developed. This service is also integrated into the BIM-SPEED platform and is available for an authorized user. These datasets can provide information about the urban context of the building. Investigating the shading effect and microclimate due to the urban heat island can be performed by accessing these datasets. Information about renewable sources of energy and their potential in the surrounding of the building, available energy networks in the district, and zip code of the building are also beneficial when there is a lack of data at the building level. The BIM-SPEED project can benefit from this tool, particularly as part of *T4.3: Acoustic, thermal comfort, and indoor air quality assessment*, *T4.4: Lighting and visual comfort assessment,* and *T4.5: Holistic performance assessment*, to get more accurate results regarding the distribution of energy networks in the district and to decrease cost by utilizing already available geospatial data. Future development for this service includes providing the accessibility to access already available raster datasets and already available maps via integration of WCS and WMS registry links in the implementation of the service.

The second methodology aims at integrating 3D surrounding building data with BEM. The method includes the conversion of data from the CityGML data model to the gbXML data schema. Future development for this approach is including vegetation and weather data in the gbXML data from available geospatial sources.

A future study in the direction of *T3.3: Integration of environmental data and GIS data to BEM* is to consider the integration of surrounding data directly from GIS to BEM via integration of GIS data with IDF file. Recently, collaborations between AEC domain software vendors such as Autodesk and GIS domain software vendors such as ESRI provided the opportunity for integration of such data, but this is not the case for the software applications and tools in energy analysis. CYPE has opened a new line of communication with one of the biggest companies in the management of geospatial data, ESRI. Their goal is to identify new opportunities to share information in both directions (BIM to GIS and GIS to BIM) by using open formats. By this, it would be possible to integrate more data from other domains aiming toward improving the results of energy analysis.

# 7. References


[1] "URSA Insulation, S.A." https://www.ursa.com/our-company/.

[2] D. M. Abdel Aziz, "Effects of Tree Shading on Building's Energy Consumption," *J. Archit. Eng. Technol.*, vol. 03, no. 04, 2014, doi: 10.4172/2168-9717.1000135.

[3] A. Saarinen, "Reduction of external noise by building facades: Tolerance of standard EN 12354-3," *Appl. Acoust.*, vol. 63, no. 5, pp. 529–545, 2002, doi: 10.1016/S0003-682X(01)00050-0.

[4] R. Hirschl, B., & Harnisch, "Climate-Neutral Berlin 2050: Recommendations for a Berlin Energy and Climate Protection Programme (BEK)," p. 24, 2014, [Online]. Available: www.stadtentwicklung.berlin.de/umwelt/ klimaschutz/bek_berlin.

[5] P. P. J. Quan, S. J., Li, Q., Augenbroe, G., Brown, J., & Yang, "Urban data and building energy modeling: A GIS-based urban building energy modeling system using the urban-EPC engine.," in *Planning support systems and smart cities (pp. 447-469).*, Springer, Cham., 2015.

[6] D. B. Crawley, "Which weather data should you use for energy simulations of commercial buildings?," *ASHRAE Trans.*, vol. 104, no. 2, pp. 498–515, 1998.

[7] L. Forejt, J. Hensen, F. Drkal, and P. Barankova, "Weather data around the world for design of field hospital HVAC," *17th Conf. proceedings, Air-conditioning Vent.*, no. 2006, pp. 49–54, 2006.

[8] M. Bhandari, S. Shrestha, and J. New, "Evaluation of weather datasets for building energy simulation," *Energy Build.*, vol. 49, pp. 109–118, 2012, doi: 10.1016/j.enbuild.2012.01.033.

[9] G. S. Golany, "Urban design morphology and thermal performance," *Atmos. Environ.*, vol. 30, no. 3, pp. 455–465, 1996, doi: 10.1016/1352-2310(95)00266-9.

[10] G. Mitchell, "Urban Development, Form and Energy Use in Buildings : A Review for the Solutions," *EPSRC SUE Solut. consortium, August 2005. Ver 1.1 2*, no. August, pp. 1–28, 2005.

[11] K. Steemers, "Energy and the city: density, buildings and transport.," *Energy Build. 35(1), 3-14.*

[12] G. M. Ascione, F., Bianco, N., Iovane, T., Mastellone, M., & Mauro, "Is it fundamental to model the inter-building effect for reliable building energy simulations?," *Interact. with shading Syst. Build. Environ. 183, 107161.*, 2020.

[13] Y. Han, J. E. Taylor, and A. L. Pisello, "Exploring mutual shading and mutual reflection inter-building effects on building energy performance.," *Appl. Energy*, vol. 185, pp. 1556–1564, Jan. 2017, doi: 10.1016/J.APENERGY.2015.10.170.

[14] Y. Ichinose, T., Lei, L., & Lin, "Impacts of shading effect from nearby buildings on heating and cooling energy consumption in hot summer and cold winter zone of China.," *Energy Build. 136, 199-210.*, 2017.

[15] Z. H. Haijing Liu, Yiqun Pan, Yikun Yang, "Evaluating the impact of shading from surrounding buildings on heating/ cooling energy demands of different community formsEvaluating the impact of shading from surrounding buildings on heating/ cooling energy demands of different community forms.," *Build. Environ.*, 2021.

[16] I. Nikoofard, S., Ugursal, V. I., & Beausoleil-Morrison, "Effect of external shading on household energy requirement for heating and cooling in Canada.," *Energy Build. 43(7), 1627-1635.*, 2011.

[17] S. J. Quan, J. Wu, Y. Wang, Z. Shi, T. Yang, and P. P. J. Yang, "Urban form and building energy performance in Shanghai neighborhoods.," *Energy Procedia*, vol. 88, pp. 126–132, 2016, doi: 10.1016/j.egypro.2016.06.035.

[18] S. J. Quan, A. Economou, T. Grasl, and P. P. J. Yang, "Computing energy performance of building density, shape and typology in urban context.," *Energy Procedia*, vol. 61, no. May 2015, pp. 1602–1605, 2014, doi: 10.1016/j.egypro.2014.12.181.

[19] J. Bhandari, M., Shrestha, S., & New, "Survey and Analysis of Weather Data for Building Energy Simulations," *J. Energy Build. 109-118.*, pp. 1–29, 2012.

[20] Z. ( Siu, C. Y., & Liao, "Is building energy simulation based on TMY representative: A comparative simulation study on doe reference buildings in Toronto with typical year and historical year type weather files.," *Energy Build. 211, 109760.*, 2020.

[21] D. J. Haberl, J. S., ONeal, D. L., & Bronson, "Impact of using measured weather data vs. TMY weather data in a DOE-2 simulation," 1995.

[22] H.-W. L. Tianzhen Hong, Wen-Kuei Chang, "ASensitivityStudyofBuildingPerformanceUsing30-YearActualWeatherData-BS2013.pdf." 2013.

[23] D. Seo, Y. J. Huang, and M. Krarti, "Impact of typical weather year selection approaches on energy analysis of buildings," *ASHRAE Trans.*, vol. 116 PART 1, pp. 416–427, 2010.

[24] N. Papakostas, K., Mavromatis, T., & Kyriakis, "Impact of the ambient temperature rise on the energy consumption for heating and cooling in residential buildings of Greece.," *Renew. Energy, 35(7), 1376-1379.*, 2010.

[25] L. Fikru, M. G., & Gautier, "The impact of weather variation on energy consumption in residential houses.," *Appl. Energy, 144, 19-30.*, 2015.

[26] J. Ohori, K. A., Biljecki, F., Kumar, K., Ledoux, H., & Stoter, "Modeling cities and landscapes in 3D with CityGML," *Build. Inf. Model.*, no. Springer, Cham, pp. 199–215, 2018.

[27] R. Liu, X., Wang, X., Wright, G., Cheng, J. C., Li, X., & Liu, "A state-of-the-art review on the integration of Building Information Modeling (BIM) and Geographic Information System (GIS)," *ISPRS Int. J. Geo-Information*, vol. 6(2), 2017.

[28] J. Hagedorn, B.; Dollner, "Integrating urban GIS, CAD, and BIM data by service-based virtual 3D city models. In Urban and Regional Data Managemen," *Urban Reg. Data Manag.*, pp. 157–170, 2008.

[29] E. Del Giudice, M., Osello, A., & Patti, "BIM and GIS for district modeling," 2014.

[30] A. Zhao, H., Nagy, Z., Thomas, D., & Schlueter, "Service-oriented architecture for data exchange between a building information model and a building energy model," 2015.

[31] P. Lapierre, A., & Cote, "Using Open Web Services for urban data management: A testbed resulting from an OGC initiative for offering standard CAD/GIS/BIM services," 2007.

[32] H. A. Brandmeyer, J. E., & Karimi, "Coupling methodologies for environmental models," *Environ. Model. Softw.*, vol. 15(5), pp. 479-488., 2000.

[33] I. Artola, K. Rademaekers, R. Williams, and J. Yearwood, "Boosting Building Renovation: What potential and value for Europe? Study for the ITRE Committee," *Dir. Gen. Intern. Policies. Policy Dep. A Econ. Sci. Policy*, vol. PE 587.326, pp. 1–72, 2016, [Online]. Available: http://www.europarl.europa.eu/RegData/etudes/STUD/2016/587326/IPOL_STU(2016)587326_EN.pdf.

[34] E. P. B. D. Recast, "Directive 2010/31/EU of the European Parliament and of the Council of 19 May 2010 on the energy performance of buildings (recast).," *Off. J. Eur. Union, 18(06)*, 2010.

[35] L. Kolbe, T. H., Gröger, G., & Plümer, "Interoperable access to 3D city models.," *Geo-information disaster Manag.*, no. Springer, Berlin, Heidelberg, pp. 883–899.

[36] "EU Project Streamer. D6.5 Advance Mapping Structures and Standards."

[37] Y. V. N. Saran, S., Wate, P., Srivastav, S. K., & Krishna Murthy, "CityGML at semantic level for

urban energy conservation strategies," *Ann. GIS*, vol. 21(1), pp. 27–41, 2015.

[38] Y. Song *et al.*, "Trends and opportunities of BIM-GIS integration in the architecture, engineering and construction industry: A review from a spatio-temporal statistical perspective," *ISPRS Int. J. Geo-Information*, vol. 6, no. 12, 2017, doi: 10.3390/ijgi6120397.

[39] J. Noardo, F., Harrie, L., Arroyo Ohori, K., Biljecki, F., Ellul, C., Krijnen, T., ... & Stoter, "Tools for BIM-GIS integration (IFC georeferencing and conversions): Results from the GeoBIM benchmark 2019," *ISPRS Int. J. geo-information*, vol. 9(9), 2020.

[40] A. Haitz, D., Geiger, "Konvertierung von CityGML-Gebäudemodellen in gbXML für energetische Betrachtungen," 2015.

[41] T. Gilbert *et al.*, "Built environment data standards and their integration: an analysis of IFC, CityGML and LandInfra," no. March, pp. 1–16, 2020, [Online]. Available: https://www.buildingsmart.org/buildingsmart-international-bsi-and-open-geospatial-consortium-ogc-release-bim-and-gis-integration-paper/.

[42] T. H. Krüger, A., & Kolbe, "Building Analysis for urban energy planning using key indicators on virtual 3D city models-The energy atlas of Berlin.," *ISPAr, 39, 145-150.*, 2012.

[43] S. Lang, *Introduction to linear algebra.* Springer Science & Business Media., 2012.

[44] P. Moseley, P., Behr, I., Cuypers, D., Op'tVeld, P., Steiger, J., Rodriguez, F., ... & Wouters, "Energy Efficiency Building-Renovation Challenge-Practical Approaches.," 2016.

[45] Fraunhofer ISI, Fraunhofer ISE, TU Wien, TEP Energy, IREES, and Observer, "Mapping and analyses of the current and future (2020 - 2030) heating/cooling fuel deployment (fossil/renewables) - Work package 3: Scenarios for heating & cooling demand and supply until 2020 and 2030 - Work package 4: Economic Analysis," no. Februar, pp. 1–157, 2017.

[46] G. Gröger, T. H. Kolbe, A. Czerwinski, and C. Nagel, "OpenGIS City Geography Markup Language (CityGML) Encoding Standard," *Open Geospatial Consort. August 2008*, no. 08-007r1, p. 234, 2008, [Online]. Available: http://www.opengis.net/spec/citygml/2.0.

[47] F. Biljecki, *The concept of level of detail in 3D city models*, vol. II, no. 62. 2013.

[48] F. Biljecki, H. Ledoux, and J. Stoter, *An improved LOD specification for 3D building models*, vol. 59. 2016.

[49] F. Biljecki, K. Kumar, and C. Nagel, "CityGML Application Domain Extension (ADE): overview of developments," *Open Geospatial Data, Softw. Stand.*, vol. 3, no. 1, pp. 1–17, 2018, doi: 10.1186/s40965-018-0055-6.

[50] V. Geiger, A., Benner, J., Häfele, K. H., & Hagenmeyer, "Thermal Energy Simulation of Buildings Based on the Citygml," pp. 295–302, 2018.

[51] P. Holcik, "Conceptual modelling and implementation of a bidirectional data interface between CityGML and EnergyPlus," 2017.

# APPENDIX 1 – CYPE SUITE MEP and GIS and environmental data integration

Group of CYPE programs are developed to carry out the thermal and energy analysis of buildings and design their lighting, sound, and fire extinguishing installations. This application works with the 3D model of the building integrated with the Open BIM workflow via the IFC4 standard. The BIM-SPEED *D3.2: A set of support tools and standardised procedures for BEM creation*, focuses on utilizing some of the software applications from this firm for BIM to BEM conversion. This section focuses on some of the contributions of the software applications implemented by CYPE in the integration of surrounding and environmental data in the process of energy modelling of the building.

## IFC Builder[7]

If the building model does not include information about the surrounding buildings, there is a possibility to define this data in the IFC Builder. IFC Builder is a free CYPE application designed for the creation and maintenance of IFC building models (Figure 21).

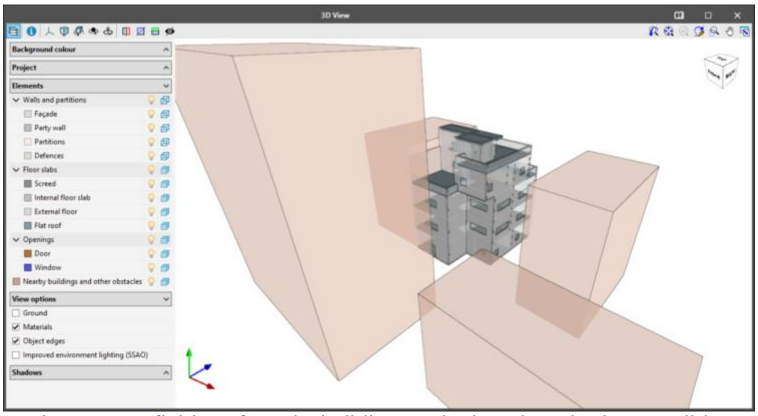

Figure 21: Definition of nearby buildings and other obstacles in IFC Builder

## Definition of nearby buildings and other obstacles in IFC Builder

Different energy analysis tools will import this data and consider it for several calculations. This information includes not only the shadows of surrounding buildings but also the shade generated by the elements of the own building (such as balconies). Moreover, it allows the possibility of modifying the geometry of the polygons that define these shadows (Figure 22).

[7] http://ifc-builder.en.cype.com/

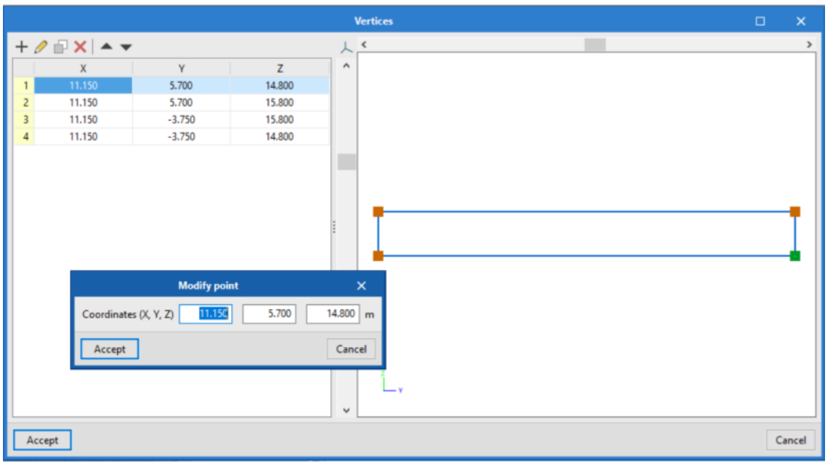

Figure 22: Adding/Modifying surrounding surfaces

Studying the possibility of considering some correction factors based on the density of buildings or the type of surface in the neighbouring area (roads, vegetation areas, and so on) is the focus for future developments. New connections with databases are under exploration to extract this data from many other formats.
The dataset generated in IFC Builder including the surrounding objects can be open and analysed in another CYPE application, 'Open BIM Analytical Model'[8], which is introduced in *D3.2: A set of support tools and standardised procedures for BEM creation*, to generate analytical geometric models of buildings to carry out energy and acoustic analysis.

## CYPETHERM LOADS[9]

Weather data is one of the requirements for energy simulation to predict energy demand and thermal loads of a building. The software CYPETHERM LOADS analyses the thermal load calculation of buildings according to the Radiant Time Series Method (RTSM) proposed by ASHRAE. By importing the weather data collected mainly in airport stations, it is possible to obtain accurate results from BEM simulation (Figure 23). The weather data in the exact location of the building may differ from the one collected in the weather station at the airport. To account for this inconsistency, the software includes a 'flexible' panel where the user can modify all the data imported to increase the accuracy of the result (Figure 24). With this information, it is also possible to create different hypothesis to test and compare the behaviour of the building with different parameters (Figure 25).

[8] http://open-bim-analytical-model.en.cype.com/
[9] http://cypetherm-loads.en.cype.com/#CYPETHERM_LOADS

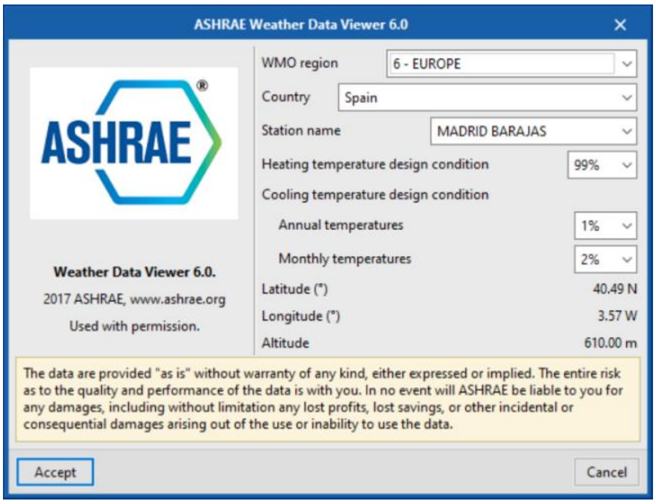


Figure 23: ASHRAE Weather Data Viewer panel

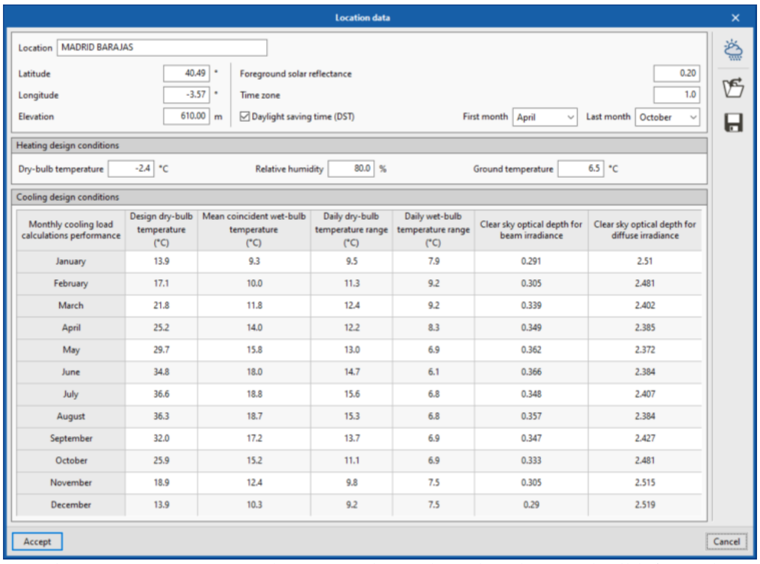


Figure 24: ASHRAE Weather Data Viewer location data – 'Flexible' panel

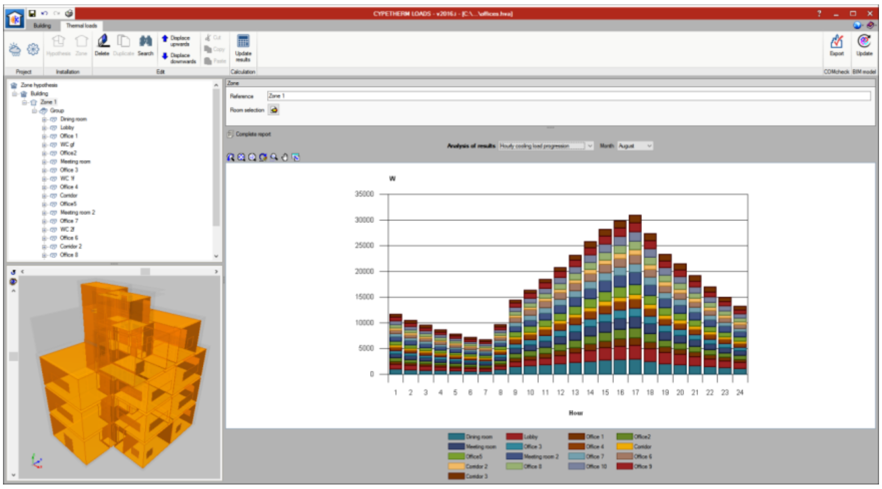

Figure 25: CYPETHERM LOADS results

## CYPETHERM EPLUS[10]

CYPETHERM EPlus is an application for the simulation and modelling of the buildings with EnergyPlus™. In this software, the weather file in the EPW file format is required for energy simulation of buildings. The user-defined data in this section include orientation, the undisturbed temperature of the soil, the solar contribution of domestic hot water, and condensation. This structure allows the adaptability of the software to the different European standards regarding some specific national weather data libraries. By this, CYPETHERM has been recognized for the generation of official building energy certifications in Spain, Italy, Portugal, and France (Figure 26).

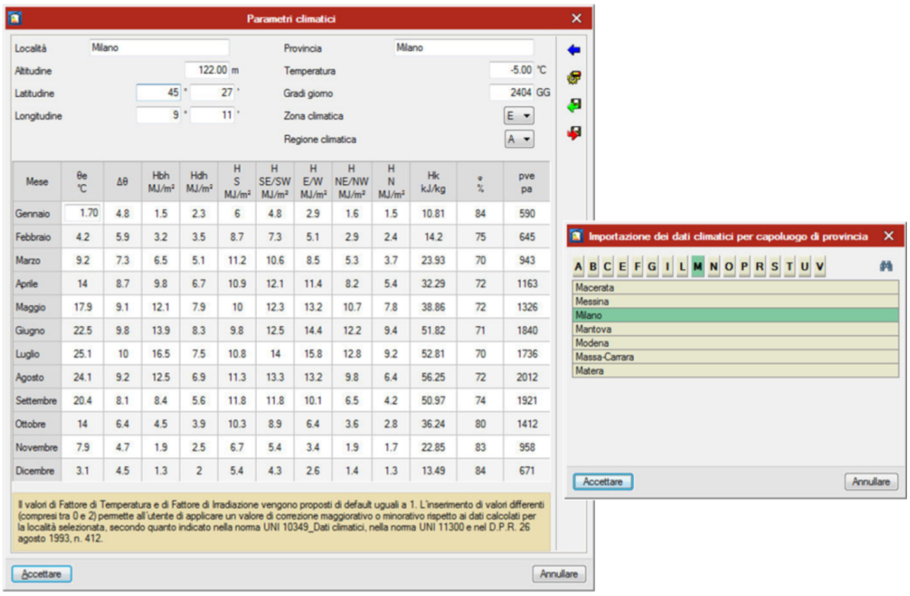


Figure 26: Weather data of CYPETHERM CE. Software adapted for the Italian market

Moreover, in accordance with Commission Decision 2013/114/EU, which establishes the guidelines to calculate the renewable energy from heat pumps following the provisions of Article 5 of Directive 2009/28/EC, three types of climatic conditions are distinguished to calculate the seasonal performance factor (SPF): average, warm and cold climate. The climate zone has been considered in the calculation of the seasonal coefficient of performance for the hot water production of the heat pumps, SCOP (DHW), in accordance with the EN 16147 code. To have the map of the climate zones of Decision 2013/114/EU defined in detail, Eurostat has established the zones.

## CYPELUX[11]

CYPELUX is a group of CYPE programs developed to carry out the thermal and energy analysis of the buildings and design their lighting, sound, and fire extinguishing installations. Lighting analysis is important for the configuration of the BEM. Daylight factor (DF) is the most widely used performance indicator for daylight. The daylight analysis does not require much information and there is no standard for exchanging this information. CYPELUX includes a control panel to define this input by different scenarios related to the

[10] http://cypetherm-eplus.en.cype.com/
[11] http://cypelux.en.cype.com/

‘Sky’ parameter: definition by altitude and azimuth and definition by date, time, and location (Figure 27). In future developments, this data could be filled by extracting this information from geographical databases linked to meteorological data where we could find the information of reflectance and common sky models according to the location.

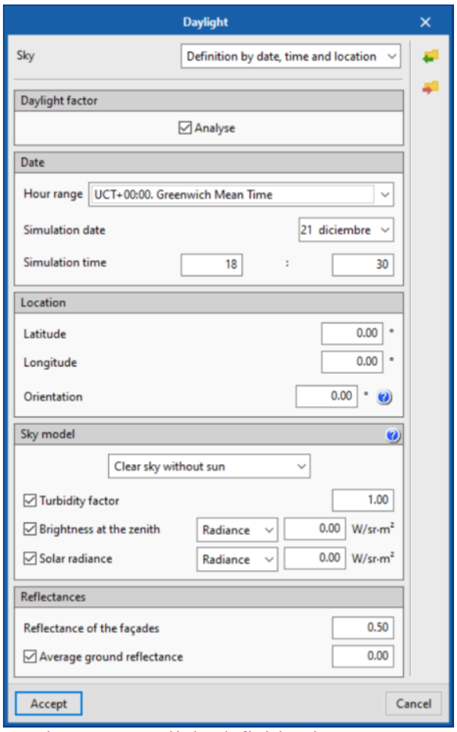


Figure 27: Daylight definition in CYPELUX

# APPENDIX 2 – An Ontology to Exploit Geospatial Data to Support Building Renovation

Figure 28 shows the object view and Figure 29 shows the process view of the ontology developed to represent surrounding geospatial and environmental concepts which are required or beneficial in building renovation projects. The ontology is assumed to help 6 use cases within different phases of the renovation workflow including:

- Site planning
- Building Energy Modelling (BEM)
- Acoustic comfort analysis
- Air quality comfort analysis
- Thermal comfort analysis
- Visual comfort analysis

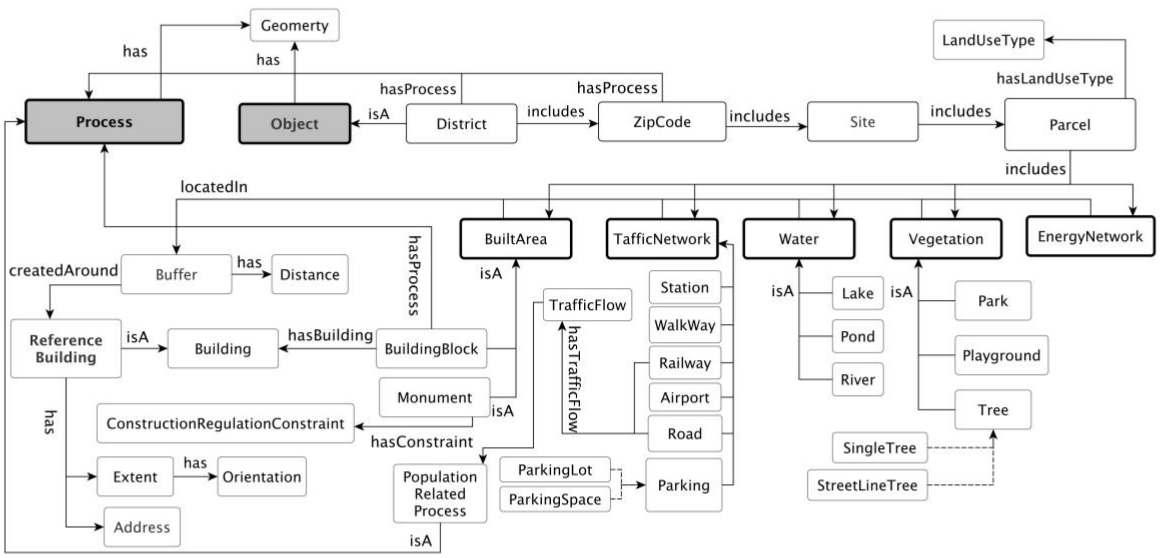


Figure 28: Object view of the ontology

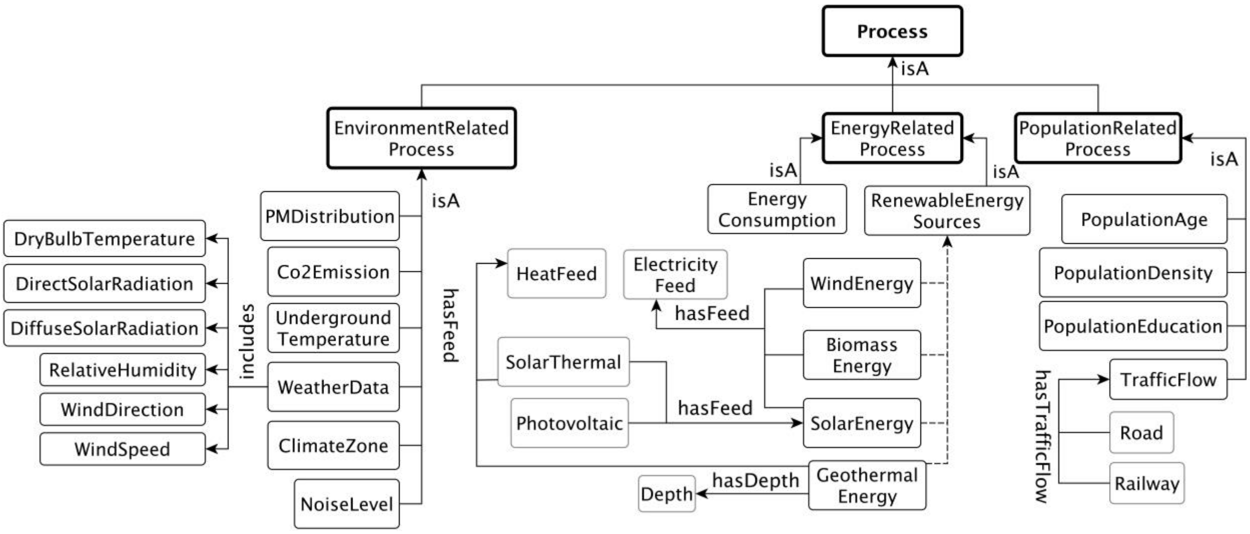


Figure 29: Process view of the ontology

# APPENDIX 3 – The gbXML data schema and the CityGML data model

## The gbXML data schema

The gbXML data schema was introduced in 1999 for transferring building information stored in CAD-based building information models to engineering and energy analysis software tools. Today, it has the industry support and has been adopted by many software solutions such as Autodesk, Trimble, and so on, and is funded now by organizations such as the US Department of Energy, Autodesk, ASHRAE, and others[12]. The gbXML schema uses XML (eXtensible Markup Language), which is a text-based computer language and is used to communicate information with little human interaction. It is possible to open an XML file in a text editor and access and understand the content easily. The gbXML is an XML file containing over 500 elements and attributes which are introduced in different tags and help the user to describe very detailed information of the building. It contains information about the location of the building on the earth defined in 'Latitude' and 'Longitude'. This information is vital when the integration with surrounding geospatial data is required. Thus, it is necessary to provide it correctly and accurately when the integration is desired.

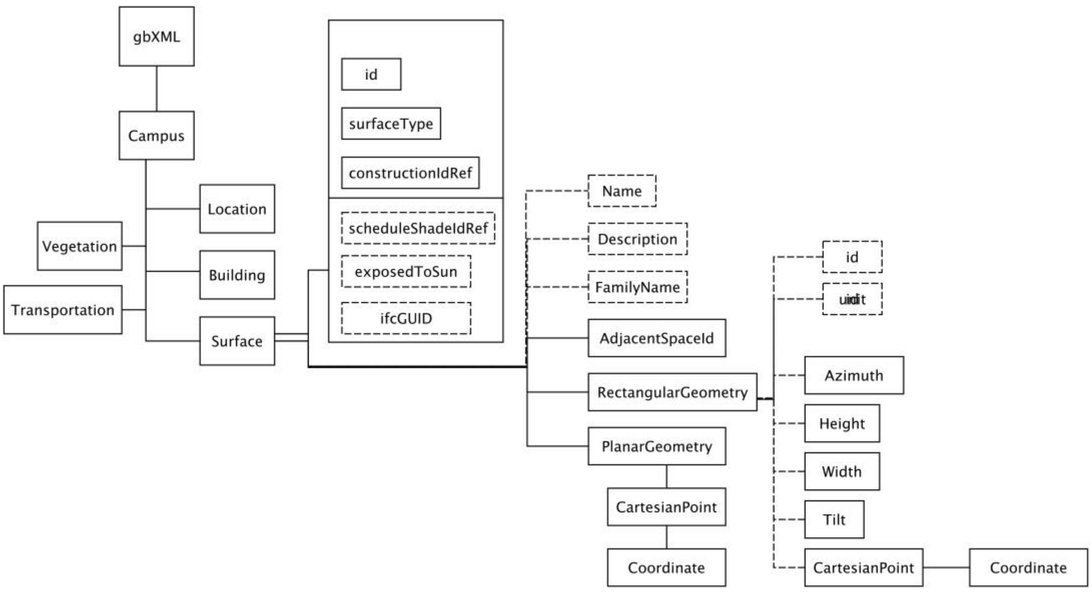


Figure 30: The gbXML Schema

Considering building objects in the gbXML data schema (Figure 30), information will be represented by the '*Campus*' element with a global child element named '*Surface*'. All surfaces in the geometry will be represented by '*Surface*'. Several attributes are assigned to '*Surface*' such as '*id*' and '*surfacType*'. The '*surfaceType*' can be selected from an enumeration list. The list consists of *InterirWall*, *ExteriorWall*, *Roof*,

[12] https://www.gbxml.org/About_GreenBuildingXML_gbXML

*InteriorFloor*, *ExposedFloor*, *Shade*, *UndergroundWall*, *UndergroundSlab*, *Ceiling*, *Air*, *UndergroundCeiling*, *RaisedFloor*, *SlabOnGrade*, *FreestandingColumn* and *EmbeddedColumn*. Based on gbXML documentation[13], '*Shade*' surfaceType is defined as a surface that is not adjacent to any spaces with a tilt between 0° and 180°. Two representations are used for each '*Surface*' named '*PlanarGeometry*' and '*RectangularGeometry*'. Within '*RectangularGeometry*' more than three '*CartesianPoint*' elements are assigned to define the surface. Each 'CartesianPoint' has a '*Coordinate*' with three values (x,y,z). The surface needs more optional attributes such as *azimuth*, *tilt*, *width* and *height* of the surface. The '*PlanarGeometry*' includes the coordinates of the cartesian points.

## The CityGML data model

The CityGML data model is an XML-based data model which is used for storing, exchanging, and representing 3D geospatial data and city models. The CityGML is an application schema for GML Version 3.1.1 which is an international standard for spatial data exchange issued by Open Geospatial Consortium (OGC) and ISO TC211.

In CityGML, there are different classes, some of which are defined in GML3, some are defined in CityGML core, and others are defined in CityGML thematic extensions (Figure 31)[14]. The thematic modules are terrain, coverages of land use, city objects, city furniture, tunnel, bridge and building, while the last three are part of '*Site*' component [46].

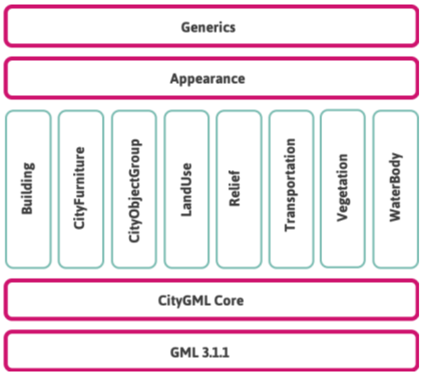


Figure 31: Generic thematic areas in CityGML

One of the characteristics of CityGML is the definition of Level of Detail (LOD). Five LODs are defined that contain different levels of detail of city objects. An example of five levels of LOD and their differences is shown in Figure 32. As shown, higher LODs can contain information regarding the texture and material of the surfaces. The concept of LOD in CityGML provides this opportunity for 3D GIS to be utilized in different applications according to the detail which is required ([47], [48]).


Figure 32: Level of detail in CityGML

[13] https://www.gbxml.org/schema_doc/6.01/GreenBuildingXML_Ver6.01.html
[14] Virtual city systems: https://vc.systems/en/#citygml

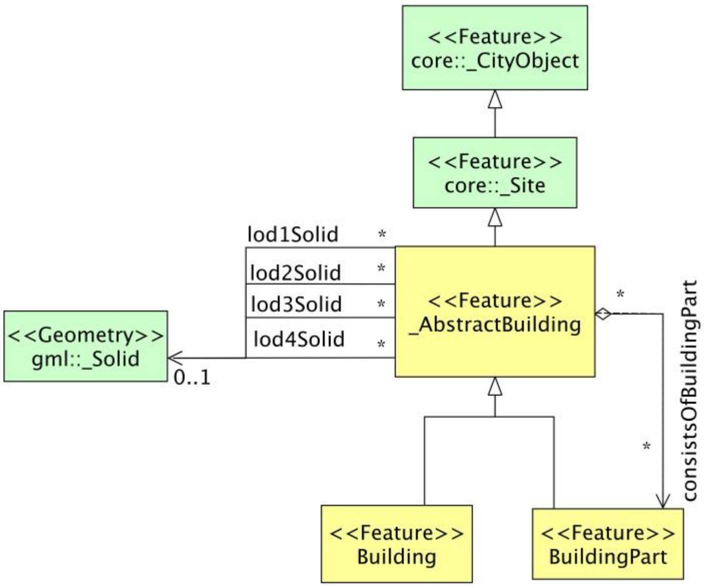

Figure 33: _AbstractBuilding in CityGML

An *_AbstractBuilding* is a sub-component of *_Site* element in CityGML and includes Building and BuildingPart features (Figure 33). *_BuildingSurface* is the elements for generating the polygons which are used to create the solid representing the building. For different LODs and consequently different details, different surfaces are assigned to a building feature. In its basic level *WallSurface*, *RoofSurface* and *GroundSurface* can create a building in LOD2 (Figure 34).

One concept in the CityGML standard is defining ADE (Application Domain Extension). The ADE is a built-in CityGML mechanism to augment the data model with additional properties related to particular use cases [49]. For instance, the CityGML Energy ADE extends the CityGML standard by features and properties which are essential for performing energy simulation [50]. There are some studies focused on transforming the data in CityGML ADE to IDF to use it in EnergPlus engine for simulation [51]. These studies were not successful in transforming surrounding buildings to IDF.

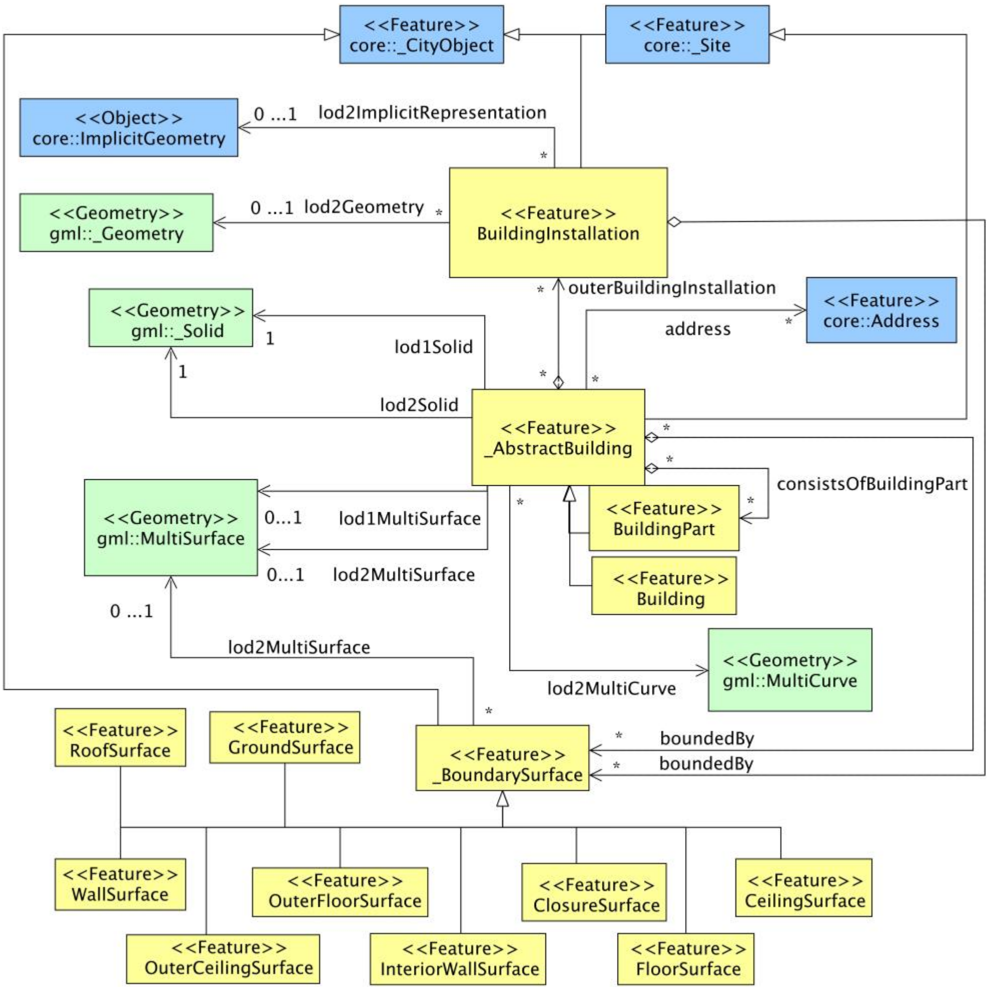


Figure 34: Surface structure in CityGML

# APPENDIX 4 – Accessibility to smart grid data

Accessibility to smart grid data in a city can be helpful in energy management and controlling energy demand concerning building renovation. One of the options to get access to such data is via web services which provide usage, generation, and feed of the energy of districts in short intervals of time. For instance, Power Grid Berlin (Stormnetz Berlin[15]) provides such a web service. The data can be acquired by sending a POST request to: https://www.vattenfall.de/SmeterEngine/networkcontrol

The service is XML-over-HTTP based. An XML body should be provided for the POST request containing information about location, the scale of data, district name, and the period. An example of such body of request for Berlin-Lichtenrade demo site is as below:

```
<smeterengine>
 <scale>DAY</scale>
 <city>BERLIN</city>
 <district name='Tempelhof-Schöneberg'>
    <time_period begin="2013-06-05 00:00:00"
                 end="2013-06-12 23:59:59"
                 time_zone='CET'/>
    </district>
</smeterengine>
```

The response is returned as an XML file that includes average load values for generation, total consumption, and feed energy from outside Berlin. Also, it includes the measured consumption of high voltage customers. The total consumption covers the consumption of high voltage customers. An example of a time interval is shown below:

```
<districtTimestampData value="2018-06-05T00:15:00+02:00">
  <usage>133.42498441</usage>
  <generation>0</generation>
  <feed>0</feed>
  <key-acount-usage>0.8375</key-acount-usage>
</districtTimestampData>
```

To check distribution and development of smart grids in Europe, European Commission mapped all the developed and under development smart grid projects within Europe[16] (Figure 35). To extract this data for Berlin, it is possible to send a request to:

https://nominatim.openstreetmap.org/search?q=berlin&limit=5&format=json&addressdetails=1

the result is a json file containing locations of smart grid projects, from OSM including longitude and latitude and more information related to the site.

[15] https://www.stromnetz.berlin/globalassets/dokumente/opendata
[16] https://ses.jrc.ec.europa.eu/project-maps


Figure 35: Smart grid projects in Europe