Large-Scale Assessment and Visualization of the Energy Performance of Buildings with Ecomaps

Project SUNSHINE: Smart Urban Services for Higher Energy Efficiency

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Abstract: This paper illustrates the preliminary results of a research project focused on the development of a Web 2.0 system designed to compute and visualize large-scale building energy performance maps, so called "ecomaps", using: emerging platform-independent technologies such as WebGL for data presentation, an extended version of the EU-Founded project TABULA/EPISCOPE for automatic calculation of building energy parameters and CityGML OGC standard as data container. The proposed architecture will allow citizens, public administrations and government agencies to perform city-wide analyses on the energy performance of building stocks.

1 INTRODUCTION

During the last years, one of the hottest topics in the information technology research area has certainly been the one about "smart-cities". But, what is a smart-city? What is its role in shaping the quality of our life?

Many definitions exist in the current literature, for example (Giffinger et al. 2010, Bowerman et al. 2000, Washburn et al. 2009, Giffinger 2007) define a smart-city in different ways, but all of them have a factor in common: the existence of an underlying ICT infrastructure that connects the physical infrastructure of the city with web 2.0 capabilities and enables innovative solutions for city management, in order to improve sustainability and the quality of life for citizens.

Typical factors that are taken into consideration when the "quality of life" offered by a city, especially a big city or a metropolitan area, is evaluated are:

- Level of urban traffic.
- Quantity and quality of green spaces.
- Public transportation efficiency.
- Level of air pollution.
- Services to citizens (schools, hospitals, etc.).

However, there are also other, less-intuitive, factors that have an impact on the overall city ecosystem. A factor that, tackled by an ICT-enabled smart approach, would increase the quality of life of city dwellers is certainly the energy consumption efficiency of residential houses. Increasing building energy efficiency would not only mean a cut-down in energy expense for citizens, but would also have an impact on the overall production of CO_2 (at energy plants) but also, less intuitively, on the city air pollution. In fact, researches conducted in this area (Fenger, 1999) demonstrated that the major causes of poor air quality are actually industries and domestic heating systems, not the quantity of vehicles circulating in the urban area, as one might more typically think.

So, how can ICT tackle this topic? What kind of smart service can be designed in order to support the increase of building energy efficiency and improve the city quality of life in this respect? What we present in this paper is a specific answer to these questions. The paper will illustrate the concept and the development of smart services which will allow to assess the energy performance of all the residential buildings in a city and to visually deliver that information with a language accessible not only to experts, but to the entire city population alike.

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The challenge is related to effectively providing these services on the whole city area, avoiding the typical discontinuous availability of energy certification of buildings. Indeed, the classical building certifications, adopted by many of EU countries, can provide a very detailed insight on building energy properties, but on the other hand, these certifications are not mandatory for all the residential buildings and their availability is thus very sparse.

The development of these services is part of the wider-scope SUNSHINE project (Smart UrbaN ServIces for Higher eNergy Efficiency, www.sunshineproject.eu), that aims at delivering innovative digital services, interoperable with existing geographic web-service infrastructures, supporting improved energy efficiency at the urban and building level. SUNSHINE smart services will be delivered from both a web-based client and a dedicated App for smartphones and tablets. In particular, the SUNSHINE platform is structured into three main scenarios:

- Building Energy Performance Assessment: Automatic large-scale assessment of building energy behaviour based on data available from public repositories (e.g. cadastre, planning data etc.). The information on energy performances will be used to create urban-scale maps to be used for planning activities and large-scale energy pre-certification purposes.
- Building Energy Performance Optimization: Assessed energy performance data will be used, together with localised weather forecasts available through interoperable web-services, to enable optimisation of energy consumption of heating/cooling systems through automatic alerts that will be sent via the SUNSHINE App to the final users.
- Public Lighting Energy Management: Interoperable control of public illumination systems based on remote access to lighting network facilities via interoperable standards, to enable optimised management of energy consumption from a web-based client as well as via the SUNSHINE App.

This paper focuses on the preliminary results for the first of the three scenarios: Building Energy Performance Assessment. As we have already hinted, the aim of the service for Building Energy Performance Assessment and Visualization is to deliver an automatic large-scale assessment of building energy behaviour and to visualize the assessed information in a clear and intuitive way, through the use of what we call Ecomaps.

Ecomaps will be publicly available via a 3D WebGL-based virtual globe that leverages on interoperable OGC standards, allowing citizens, public administrations and government agencies to evaluate and perform analysis on the building energy performance data.

Having a clear and self-descriptive view of the energy efficiency state of a city building stock makes it possible to plan infrastructural maintenance activities to increase the overall energy efficiency, allow citizen to save more money and, ultimately, improve the air quality of the city.

2 STATE OF THE ART

The current availability of relevant technologies and standards has encouraged the development of many research projects in the area of building energy performance estimation based on publicly available data. These data generally do not include all the information needed for the energy performance calculation regulated by the 2006/32/CE directive, so one of the most critical aspects for these type of projects is how to estimate the missing information in a reliable way, using the basic input data that is typically available, such as building geometry, building use, construction year, climatic zone, etc.

A common and powerful approach to the problem, as described in (Nouvel et al., 2013), is to use the CityGML (City Geography Markup Language) OGC standard (Gröger et al., 2008) to semantically describe the set of objects that compose the urban environment, exploit a building typology database (such as the outcome of TABULA project, Ballarini et al. 2011) to statistically estimate the energy performance properties of buildings and, finally, define an Application Domain Extensions (ADE) to store the estimated information in the GML of each building (Carrión et al. 2010, Kaden et al. 2013, Krüger et al. 2012).

A radically different approach is described in (Hay et al., 2010), where operational energy performance of buildings is estimated from thermal images acquired by airborne thermal cameras.

Both approaches have pros and cons: in the former case, input data are publicly available, requiring no additional cost; the main limit is instead represented by the energy performance estimation process that takes into consideration only residential buildings (other typical building use typologies are offices, schools, sport facilities, warehouses, factories, etc.). Moreover, the overall software architecture is typically desktop based, so the access to the results is often limited to a small number of users with advanced GIS skills. Another limit is related to the dissemination and exploitation activities of the computed results: for performance reasons, the visualization of CityGML encoded data is commonly provided via a conversion to KML (Wilson, 2008), where the link between the building performance data and its geometry is colour-coded in each building-style parameter and the other information stored in the starting CityGML file is lost.

In the thermal image approach, instead, all the building use typologies are taken into consideration, but the cost to collect thermal images to cover an entire city is hardly negligible. Furthermore, only the roof surface is evaluated in terms of energy performance, ignoring the full contribution of walls. Moreover, the use of proprietary standards does not encourage the adoption of the same solution by the research community.

3 SUNSHINE APPROACH

3.1 Architectural Concept

In this chapter, the system architecture of the SUNSHINE platform is presented. As reported in the introduction, the SUNSHINE project covers three different scenarios; however, given the focus of the paper on the first scenario, the system architecture description has been rearranged to focus on the components that are meaningful in this context.

The chosen approach for this scenario was that of leveraging on a building typology database and the system architecture that has been designed to comply with it (see Fig. 1) is based on a Services Oriented Architecture (SOA) with three tiers (data, middleware and application layers). A SOA-based approach allows accessing to the resources through a middleware layer in a distributed environment and thus avoids single access-points limitations that are instead typical for desktop-based architectures.

3.1.1 Data Layer

The bottom level of the SUNSHINE system architecture is aimed at storing geometry and semantic information about buildings and thematic raster data. The two fundamental components of this layer are the 3D CityDB and the raster map repository.

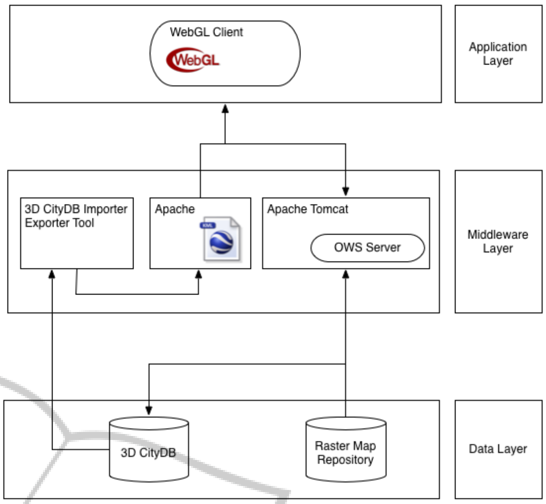

Figure 1: System Architecture.

The 3D City Database (Stadler et al., 2009) is a free 3D geo database designed to store, represent, and manage virtual 3D city models on top of a standard spatial relational database. The database model contains semantically rich, hierarchically structured, multi-scale urban objects facilitating GIS modelling and analysis tasks on top of visualization. The schema of the 3D City Database is based on the CityGML standard for representing and exchanging virtual 3D city models.

The 3D City Database is described via a PostGIS relational database schema and specific SQL scripts are provided to create and drop instances of the database on top of a PostGIS DBMS. The main features of the 3D City Database are:

- Semantically rich, hierarchically structured model.
- Five different Levels of Detail (LoDs, see Fig.2).
- Appearance data in addition to flexible 3D geometries.
- Representation of generic and prototypical 3D objects.
- Complex digital terrain models (DTMs).
- Management of large aerial photographs.
- Version and history management.
- Matching/merging of building features.
- Works with PostGIS 2.0 or higher.
- Open source and released under the terms of the GNU Lesser General Public License v3 (LGPL).

The raster map repository is a data file store aimed at containing geo-located orthophoto and elevation files in raster file format.

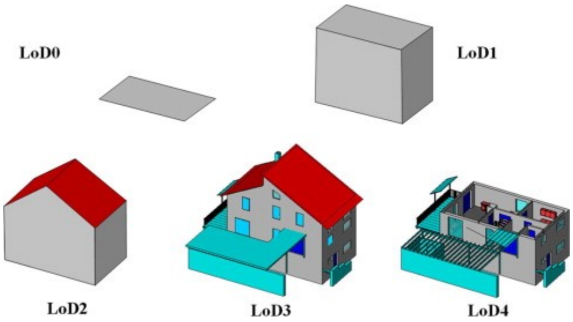

Figure 2: CityGML LOD example.

3.1.2 Middleware Layer

The middleware layer is the core component of the SUNSHINE platform. Its duty is to manage the connection between the application layer and the data layer, providing access to the resources stored in databases and map repository. The middleware layer is composed by the 3D CityDB Importer/Exporter Tool and Apache Tomcat.

The 3D CityDB Importer/Exporter Tool allows interacting with the 3D City Database or external data and has the following specific features:

- Full support for CityGML 1.0 and 0.4.0.
- Exports of KML/COLLADA models.
- Generic KML information balloons.
- Reading/writing CityGML instance documents of arbitrary file size.
- Multithreaded programming facilitating high-performance CityGML processing.
- Resolving of forward and backwards XLinks.
- XML validation of CityGML documents.
- User-defined Coordinate Reference Systems.
- Coordinate transformations for CityGML exports.
- Matching/merging of building features.
- Open source and released under the terms of the GNU Lesser General Public License v3 (LGPL).

The Apache Tomcat (Apache Community, 2014) is an open source software implementation of the Java Servlet and JavaServer Pages technologies.

3.1.3 Application Layer

A further challenge that the SUNSHINE project took into high consideration is the dissemination and exploitation of the reached results. A smart-city will become smarter only if all the involved stakeholders (citizens, public administrations and government agencies) are aware about the outcomes of the research activities in that particular scope. For this reason, a great effort was put in designing and implementing a client platform that would be usable by the majority of devices, both mobile and desktop-based.

To achieve the widest dissemination possible for the project's results, the emerging WebGL technology (Marrin, 2011) has been employed, in conjunction with HTML5 elements, as the main component of the application layer. WebGL is a cross-platform royalty-free web standard for a low-level 3D graphics API based on OpenGL ES 2.0, exposed through the HTML5 Canvas element as Document Object Model interface.

3.2 Ecomap Generation Workflow

The aim of this section is to describe how each building is associated with an energy class index. The energy class is an index describing the energy performance of a building and it is usually computed from a series of detailed information on building energy properties that are not available in general as public domain data. Publicly available data is usually limited to more basic information, such as building geometry, year of construction, number of building sub-units, etc. So, the approach we followed was to estimate the energy parameters needed for performance calculation from the few publicly available data and to do so we leveraged on the outcomes of project TABULA (Loga, 2010).

Project TABULA had a two-fold aim:

- Define a set of building typologies for each of the countries participating into the project. Each country defined a classification of its building stock basing on 4 parameters: country, climate zone, building construction year, building size type. A building stereotype, described in all its energy properties, is associated to each class, with the aim of representing the average energy behaviour for buildings of that class.
- Define a common set of parameters to describe the energy behaviour of buildings and a coherent common energy balance method, in accordance with field standards ISO 13790, ISO 15316. In this way the procedure can be applied to the entire national building categories and provide a common framework of reference to compare computed energy performance parameters.

So, if data are available on country, climate zone, construction year and size type for a building, than, via the use of TABULA, it is possible to associate the building to a specific typology class and thus to its corresponding building stereotype and its energy performance properties, including estimated energy performance class that will then be shown via the ecomap.

However, it is to be noted that the building classification defined in TABULA currently applies specifically to residential buildings and thus cannot be used to assess the energy performance of buildings with a predominant use that is other than residential (commercial, administrative, industrial, educational, etc). As a consequence, the ecomap itself will carry information only for residential buildings. This seems to us a reasonable compromise as residential buildings are among the major causes for energy consumption and air pollution (Fenger, 1999). It is also to be stressed that the ecomap, that is the display of the energy performance classes of residential buildings as estimated via the use of building typology stereotypes, is a statistical representation of the residential building energy condition, so its intrinsic value lies on the overall picture that it provides, not on the accuracy of the estimation for any given specific building.

In order to evaluate the validity of our approach we foreseen to compare the simulation results with the information available from the existing energy certificates for a statistically meaningful number of buildings.

Fig. 3 shows the workflow diagram for the ecomap generation procedure. The inputs to the procedure are:

- A LoD-1 CityGML model, containing the information on building geometry and spatial distribution;
- Mandatory building data: country, climate zone, building main use (residential, non-residential), year of construction;
- Optional building data: refurbishment level (none, standard, advanced), storey height, number of floors;
- Building typology stereotype data. One building typology stereotype for each class defined by: country, climate zone, period of construction, building size type, refurbishment level.

It can be noted that the information about building size type class is necessary to identify the proper corresponding building stereotype, but it is not among the requested input building data. TABULA identifies four building size type classes for residential buildings: single-family house, multi-family house, terraced house and apartment block. This kind of data typically is not publicly available, but it can nonetheless be estimated from the available building data.

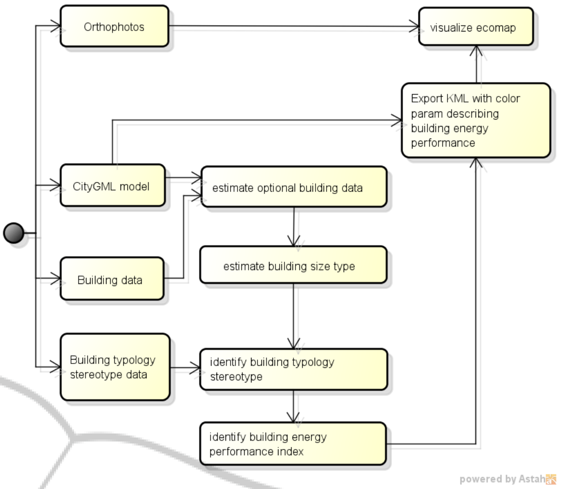

Figure 3: Ecomap workflow diagram.

The simple and clear-cut approach that we have taken to estimate building size type from the other data is described in Fig. 4. Only three parameters are taken into consideration: building isolation (derived from knowledge on footprint reciprocal position), footprint surface and number of floors above ground. The information about storey height and number of floors is either part of the provided input or estimated during the building size type estimation phase by assuming a storey height of 3 meters. The thresholds for the number of floors above ground include the mansard space that is usually present in buildings with sloping roofs. This is a consequence of LoD-1 building geometrical model that includes mansard space as an integral part of the building.

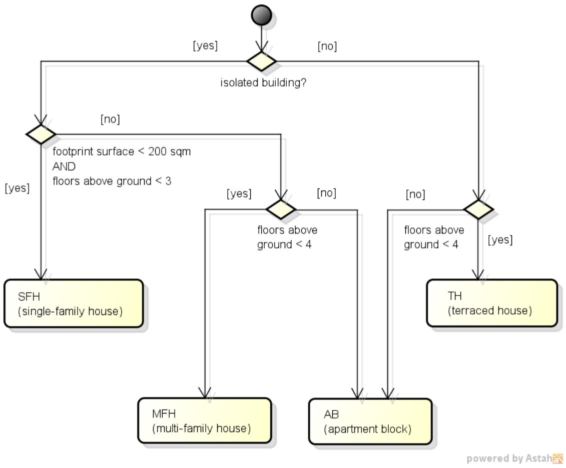

Figure 4: Building size type estimation.

Finally, the estimated data about building size type is used to identify the proper building stereotype from the available typology classes. If the information about refurbishment level is not provided in input, than it is assumed that no refurbishment activity has been performed on the building. From that, the energy performance parameters are derived, including the energy performance class index to be shown in the ecomap.

3.3 CityGML Extension for Building Energy Performance Data

This section is intended to provide a more detailed view of the attribute list that we defined for describing building energy-related properties. As Tab. 1 shows, attributes include both input and output data to the ecomap generation procedure.

The first sets of attributes store the mandatory input data (country, climate zone, building main use and construction period) and the optional input data (refurbishment level, storey height, number of floors, number of sub-units). As discussed in the previous section, the latter are either provided by the user or estimated during the workflow execution. From these attributes and by the use of TABULA building typology database, the appropriate value for the building size type is identified.

The following sets of attributes in the table describe the thermal-related properties of the building: the envelope heating balance (mean envelope heat transmission coefficient, heating comfort temperature, heating season start and end) and the systems performance (heating system type, main heating controls, hot water preparation system type, ventilation system type). The values assigned to those attributes are taken from the TABULA building stereotype corresponding to the building typology class the building belongs to. Those attributes are the base for the computation of the energy performance parameters for the building, according to TABULA common energy balance computation procedure.

The final sets of attributes store the computed energy performance parameters: energy need (for space heating and hot water preparation) and delivered energy (for space heating, hot water preparation and for auxiliary systems). Different choices can be made about which of those attributes or combination thereof to use as a cumulative index for the energy performance of the building. Energy need refers to the net energy needed to maintain thermal comfort, while delivered energy is the actual energy delivered by the energy distributor that takes also into account the efficiency of heating/hot water systems in producing the energy needed to maintain thermal comfort. So, the choice of referring to delivered energy is the most reasonable if comparison between estimated and measured consumption are foreseen, as it is the case in the SUNSHINE project. Indeed the possibility to compare the estimated values with the measured ones in a number of pilot buildings is an important target of the project in order to assess the validity of the estimation process.

Table 1: Building energy performance attributes.

Attribute Name	Type
Country	string
Climate zone	string
Building main use	string
Construction period	string
Refurbishment level	string
Storey height	real
Number of floors	integer
Number of sub-units	integer
Building size type	string
Mean envelope heat transmission coefficient	real
Heating comfort temperature	real
Heating season start	date
Heating season end	date
Heating system type	string
Main heating controls	string
Hot water preparation system type	string
Ventilation system type	string
Energy need for space heating	real
Energy need for hot water preparation	real
Delivered energy for space heating	real
Delivered energy for hot water preparation	real
Delivered auxiliary energy	real

Our choice of attributes is in line with the results of other research activities, such as (Dalla Costa et al., 2011). However, while that research focuses on providing an attribute schema that can accommodate for building energy performance analysis on different level of aggregation (sub-unit, building, block, etc), our choice of attributes has been done having in mind a building centred approach as this is the aim of the SUNSHINE project.

3.4 Ecomap Visualization via WebGL

As described in the previous section about system architecture, via the WebGL-enabled visualization the project stakeholders can easily discover, compare and perform statistics on the estimated ecomap data by accessing to a classical HTML web page.

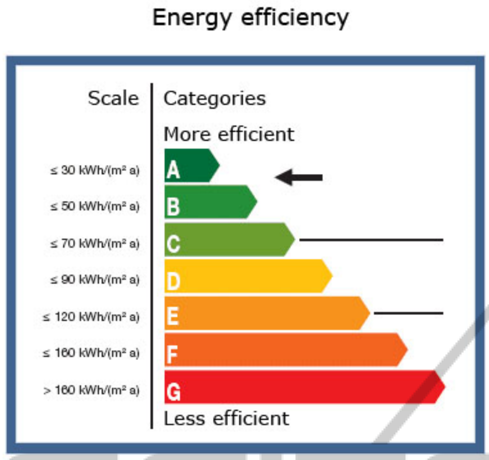

Figure 5: Building colour-coding scale.

Ecomaps are generated merging geometry LOD-1 information from the CityGML of the displayed city with the output of the energy performance estimation procedure. More specifically, the colour of each extruded KML polygon will be dependent on the estimated building energy class. The reference between each building in the KML file and the corresponding building in the 3D CityDB is ensured by storing the unique GML UUID of the building in the KML polygon name property. By the use of a web service it will then be possible to retrieve the energy-related parameters corresponding to the selected object.

The following code shows an example of how each building is specified in the KML file.

```
<Style id="F">
    <PolyStyle>
      <color>FF0000FF</color>
      <fill>1</fill>
      <outline>0</outline>
    </PolyStyle>
  </Style>

<Placemark>
      <description>Building extruded
test 1</description>
      <name>UUID_a2017297-d0cf-45ee-
ae6d-94a5d4fcda03</name>
      <styleUrl>#F</styleUrl>
      <Polygon>
<altitudeMode>absolute</altitudeMode>
     <extrude>1</extrude>
     <outerBoundaryIs>
       <LinearRing>
         <coordinates>
11.1263299929,46.0683712643,213.486
11.1263070656,46.0684180254,214.313
11.1262141309,46.0684011600,208.837
11.1262401711,46.0683529640,213.74
11.1263299929,46.0683712643,213.486
         </coordinates>
       </LinearRing>
     </outerBoundaryIs>
   </Polygon>
</Placemark>
```

Referring to the code listed above, the first part is used to make a visual representation of the energy class determined by the estimation procedure. Fig. 5 shows the colour coding of each building geometry based on its estimated energy class. The second part of the KML code is used to describe the extruded geometry of each building contained in the source file.

As Fig. 6 shows, the ecomap visualizer is composed by two interconnected parts:

1. An HTML5 canvas that displays the WebGL virtual globe in which KML ecomaps, based on CityGML LOD-1 geometries, are loaded;
2. A classical HTML tab, displaying the detailed energy data corresponding to the selected building. Comparisons between building energy efficiency characteristics can easily be performed using the "radar" diagram placed in the bottom-left part of the page. The diagram allows the comparison of the most important building proprieties between the current and the previously selected building.

Figure 6: Ecomap visualization.

4 CONCLUSION AND FUTURE DEVELOPMENTS

In this paper we have presented some of the preliminary results of the SUNSHINE project. The use of the TABULA building typology database allows for a large-scale application of the building energy performance assessment and the underlying service-oriented system architecture supports a distributed access to the related services. Moreover, the use of the emerging WebGL technology ensures the largest available audience in terms of devices, both desktop and mobile, avoiding the development of device-dependent custom clients for 3D city map visualization.

Future developments on the building typology side will be linked to the efforts of the EPISCOPE project extending the results of TABULA project to additional European countries and to building with predominant use other than residential. In particular a deeper investigation on the influence of the shape factor of the building (Waste surface/Volume) should be performed in order to improve the classification especially in specific urban context. On the side of data structure and visualization, improvements will be focused on increasing the quality of the geometry displayed, making it possible to render buildings based on CityGML LoD-2 level of detail and on the development of more detailed building size type estimation procedures.

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