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# District data management, modelling and visualization via interoperability

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## Abstract

Data management has been one of the most interesting research fields within the smart city framework over the last years, with the aim of optimizing energy saving at district level. This topic involves the creation of a 3D city model considering heterogeneous datasets, such as Building Information Models (BIMs), Geographical Information Systems (GISs) and System Information Models (SIMs), taking into account both buildings and the energy network. Through the creation of a common platform, the data sharing was allowed starting from the needs of the users, such as the public administrator, the building manager and the energy professional. For this reason, the development of a District Information Modelling (DIM) methodology for the data management, related to the energy saving and $CO_2$ emission, is considered the focus of this paper. It also presents a specific tool developed for the comparison of energy data in a selected district: the Benchmarking Tool.

## Introduction

Nowadays, the increasing amount of district-related data available within the cities requires the development of systems able to integrate data coming from heterogeneous sources, developing a “built environment information system” (Pasquinelli, 2016). In this context, virtual 3D city models are in the research focus; with the growing availability of 3D city models conforming the standard CityGML (City Geography Markup Language), a full coverage of city objects of the entire urban area has been provided. (Kruger & Klobe, 2012). As time went by, the need of collecting and storing specific information on buildings increased; the limit of the process mentioned above is the fact that the CityGML language does not provide explicit attributes for modelling energy consumption of buildings (Kruger & Klobe, 2012). For this reason, several attempts have been made in order to integrate data coming from the standard CityGML and building models. One of the first examples is an approach for data integration based on a Unified Building model (UBM) which encapsulates both the CityGML and IFC models, thus avoiding translations between the models and loss of information (El-Mekawy, 2012). Another approach aims to convert already existing architectural models, stored in the IFC format, into CityGML models; the result of this study was a conversion algorithm that accurately applies the correct semantics from IFC models and that constructs valid CityGML LOD3 buildings by performing a series of geometric operations in 3D (Donkers, 2015).

Several projects have been recently developed in order to face the lack of systems where all district and building-related data is collected in a common digital repository. In general, the aim is to develop the knowledge, strategies, decision support tools to monitor and assess actual building performance, considering relevant factors such as user behaviour, complex energy system performance and weather forecast, and to be able to predict accurately building energy loads and consumption along the whole lifecycle (Romero, 2016). Within this context, the European 7th Framework Programme (EU FP7) DIMMER project (District Information Modelling and management for Energy Reduction) aims at managing all district-related data through the DIMMER platform, available to all the stakeholders involved at the district level. The interoperable process makes the data exchange possible. The starting point of the DIMMER methodology is the definition of District Information Modelling (DIM), which means extending the Building Information Modelling (BIM) at the district scale. The main challenge to face when creating District Information Models (DIMs) concerns the ability to manage a big amount of data, coming from different domains. In this field, interoperability plays a key role for data exchange among different domains (Rapetti, 2016).

The data visualization is another key point from DIMMER’s point of view. Therefore, three visualization tools have been developed: the Dashboard, the District Visualizer and the Benchmarking Tool. In the present paper the focus is on the Benchmarking Tool, which enables the visualization of data coming from several domains (GIS, BIM etc.) extracted from the DIMMER platform and includes a simulation engine to perform energy simulations. The DIMMER project had two pilot cities: Manchester and Turin; for each city a specific number of case studies were selected in order to enhance the replicability of the DIM methodology.

## Related works

A considerable number of projects developed at urban scale aims at creating platforms/tools, useful to visualize energy-related information and perform energy simulations.

Under the EU FP7 INDICATE (Indicator-based Interactive Decision Support and Information Exchange Platform for Smart Cities) smart cities project, a decision support masterplanning tool will be developed, which will; plan, integrate and optimize the sub-systems of the overall city system: The INDICATE tool will achieve this through the integration of real data from a city with the dynamic simulation software, the IES <Virtual Environment>, 3D Urban CAD modelling tools, the ESRI CityEngine package, and Sustainable Urban Indicators, to create a Virtual City Model. This will provide a 3D model of the city, its networks and its buildings, ready for urban simulation (Melia, 2015).

The aim of the OPTIMUS (Optimising Energy Use in Cities through Smart Decision Support Systems) project, funded under the EU FP7 between 2013-2016, is to support the decision making process, improving the energy efficiency of buildings, by optimizing the energy use in their premises, and reducing $CO_2$ emissions. The result of the OPTIMUS project is a package of web-based consulting tools for energy managers and energy consultancies, in order to make cities more energy efficient and sustainable. One of these technological outputs of the project is a semantic framework which enables cities to share and integrate their data from different domains, using Semantic Web technologies. (Sicilia, 2015)

The “Optimised Energy Efficient Design Platform for Refurbishment at District Level” (OptEEmAL) project is funded under the European Union’s Horizon 2020 research and innovation programme. The platform delivers an optimised, integrated and systematic design based on an Integrated Project Delivery (IPD) approach and supported by the utilization of BIM models for an integrated, optimized and systemic energy oriented refurbishment at district level. This is achieved through development of holistic and effective services platform that involves stakeholders at various stages of the design while assuring interoperability through an integrated ontology-based DDM (District Data Model) (Romero, 2016).

The aim of the “Decision support Advisor for innovative business models and user engagement for Smart Energy Efficient Districts” (DAREED) project is to reduce energy consumption in buildings by using Information and Communication Technologies (ICTs), anticipating savings of between 7% and 10%. To achieve this DAREED will create a system capable of receiving information from various sources, analyze the energy consumption taking place, and provide information and advice to both citizens as utilities and public institutions, involving all stakeholders in the process of improving energy efficiency. (Wicaksono, 2016)

The EU FP 7 Project “Intelligent Neighbourhood Energy Allocation & Supervision” (IDEAS) aims to demonstrating how energy positive neighbourhoods (EPN) can be cost effectively and incrementally implemented by designing, testing and validating various software tools and user interfaces. The primary intended user of the tools developed in the IDEAS project is a new type of actor, the Energy Positive Neighbourhood Service Provider (EPNSP, described in Crosbie, 2014). The IDEAS project shared 3D virtual space is used to demonstrate the Energy-Positive Neighbourhoods (EPN) concepts to remote visitors. The idea is to provide remote visitors with a virtual venue to learn about the IDEAS project, an immersive rich collaborative environment without the need to actually visit the project pilot site. A unique aspect of the virtual environment is the incorporation of simulated energy production and storage elements into the neighbourhood representation that do not exist in the real sites, and to show how these are integrated into the intelligent energy management that is developed as part of the IDEAS project. (Short, 2014).

Comparing DIMMER with the projects described above, the real innovation is in the use of different entities (e.g. BIM, SIM, GIS) to develop DIM. While CityGML and IFC have been used within the mentioned projects, for the DIMMER project the JSON (JavaScript Object Notation) language is used. The novelty of the DIMMER framework consists of an IoT platform based on open standards of the Web, which creates a single district parametric model. Data has been integrated and correlated together with information on buildings. Thanks to the use of web services this paper shows an application of the DIMMER platform focused on modelling, through the DIM standard definition, and data visualization, through the Benchmarking Tool, which is at the same time a viewer and a simulation engine. The strength of the Benchmarking Tool is the fact that its functionalities are linked to real-time data. Furthermore, the BIM model visualization is possible through a graphic interface considerably communicative, so not only professionals can use and understand it, but building managers and citizens too. Users’ awareness is one of the essential topic of the DIMMER project, which aims at engaging common users’ in the process of developing “Smart cities”.

## Methodology

### 3D district modelling

3D district modelling is immensely useful to visualize characteristics and features and collect information about existing districts. Furthermore, on the one hand it facilitates the understanding for the public, on the other hand it plays a support role in rational allocation of urban planning. The focus of the DIMMER project is on the use of BIM methodology to perform urban analyses for energy saving. For this reason, it is necessary to simplify the building information model in order to have, as a result, a model useful from a district point of view. *Figure 1* shows the framework of the DIMMER platform, which includes several layers corresponding to specific domains, represented as under a “press”. Starting from GIS and SIM domains and adding BIM it was possible to develop a DIM model. The results of the DIMMER platform can be

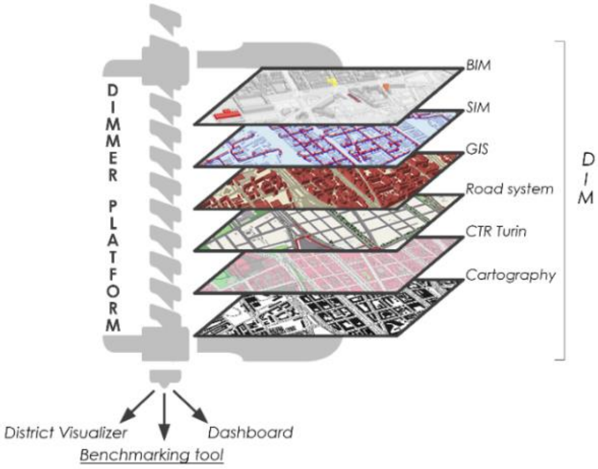

*Figure 1: The DIMMER platform. Services and tools*

visualized using three different tools: District Visualizer, Dashboard and Benchmarking Tool; however, the focus of this study is on the last tool. Within the DIMMER project, a standardization of the process leading to a DIM model has been defined. The framework of the methodology followed is visible in *Figure 2*; the starting point of the process, within the BIM domain, is the definition of the template and subsequently the shared parameters and the material library to apply to the BIM model. Once the definition of the standardization process is fulfilled, it is possible to start modelling, applying the standard previously defined. The BIM model is first of all a database; therefore, schedules and other information can be extracted and used for several purposes. As far as the energy analysis is concerned, it is necessary to define Rooms within the model; this way the connection with the Energy Analysis Model (EAM) domain is ensured, in particular using the Green Building XML (gbXML) as exchange format. The gbXML schema was chosen as exchange format because it was developed to facilitate the workflow of information from BIMs to performance energy analysis tools; in this case the standard Industry Foundation Class (IFC) is not useful because it does not keep the information relevant to the energy analysis. If the model is not perfectly imported, it requires a “gbXML loop”, useful to set the model properly before performing energy simulation. Urban analysis is not the only objective of the DIMMER project to be achieved through the use of BIM for DIM. It is also essential that the models and information can be shared among the partners of the project and exported using several file formats. The DIMMER system is based on the middleware, which is a digital data repository where models are stored or retrieved using different exchange formats. In this case, the BIMs have been exported and uploaded in the middleware adopting the following formats: i) gbXML; ii) IFC; iii) Filmbox (FBX), a proprietary file format used to provide interoperability between digital content applications; iv) Open DataBase Connectivity (ODBC); v) Revit native format (RVT).

The reason why several formats were uploaded is related to the different uses of BIM for DIM, as far as geometrical and alphanumerical data is concerned. In order to provide as wide as possible access to the essential information related to the case studies, it is fundamental to correctly input the parameters that will be shared in the BIM. In other words, since the beginning of the entire process, besides the geometrical data, it is necessary to input those parameters useful to perform energy simulations, e.g. the thermo-physical features of the materials or the dimensions of the radiators. In order to perform the energy consumption assessment of urban districts, firstly it is necessary to build reliable energy models of each building. The models have to be calibrated comparing the results of the simulations with the real data of the consumptions and the indoor temperatures, monitored by sensors and meters installed in the buildings selected as case studies. The validation of the energy models is achieved through an iterative process aimed to calibrate the parameters of the envelope and the systems. In particular, the thermo-physical properties of the material are inferred on the basis of the construction period of the building, while the technical data of the systems is collected from the project or on-site by reading labels of the various components of the system (e.g. boilers, heat exchanger, fan coils, etc.).

The BIM models have been developed using the software Autodesk Revit 2016, which allows the

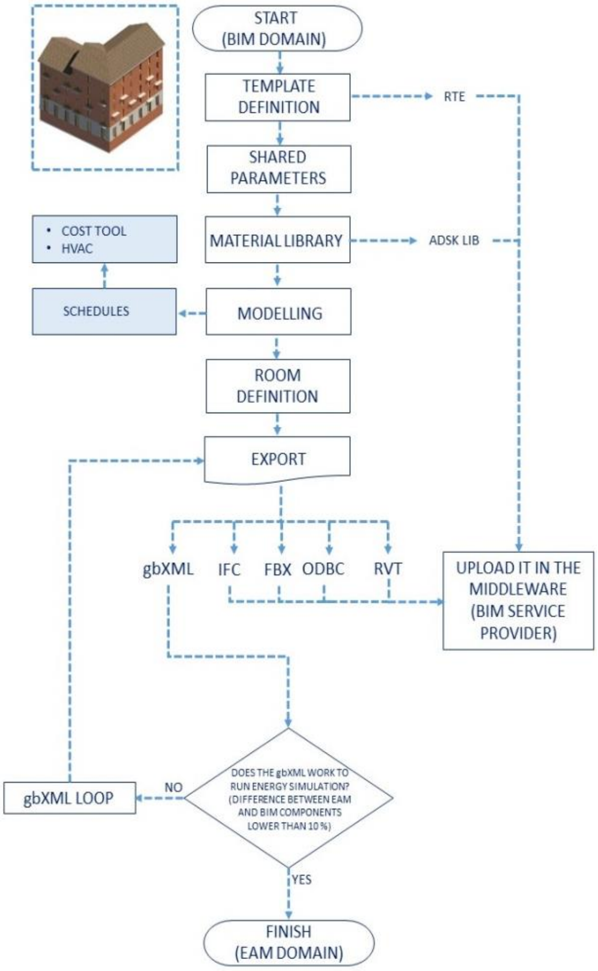

*Figure 2: The BIM domain workflow*

creation of an energy model, useful to prepare the model for following energy simulations. As far as the BIM is concerned, it is important to note that it is worth keeping only elements relevant to the Green Building XML (gbXML) format: it follows that stairs and railings, for example, are not considered. Some deeper instructions on how to standardize the DIM includes the following: i) windows must be at least 10 cm higher than the ground level; ii) floor objects must be modelled following the centreline of walls; iii) the room bounding of architectural pillars must be disabled; iv) underground floors are better recognized if they are located on the same level. Several information “fields” (specific term used to define information that can be added to schedules) can be added to the BIM; the use of key schedules resulted in the ability to make calculations within Revit. For this reason, data such as the dimensions of water radiators were used in order to calculate the nominal capacity and flow rate for each radiator. Furthermore, through key schedules, it was possible to calculate the costs related to possible refurbishment strategies. One essential step is the definition of Rooms within the model, because it is a paramount step in order to export the gbXML format. Once the rooms are defined, it is possible to create a Room Schedule, which is necessary for linking further information. For example, it is possible to implement the energy model for energy simulation, thanks to a key schedule which shows calculation for nominal capacity [W] and flow rate [Kg/s] of the radiators in each room. Finally, when exporting the gbXML, it is essential to include thermal properties.

The final goal of urban energy analyses is the validation, which is achieved through the calibration of the model. This means that the validation needs an iterative process of comparing the model to actual system behaviour in order to refine the model in a step by step manner. Furthermore, several scenarios (potential refurbishments aiming at increasing efficiency) have been hypothesized. The first strategy includes the addition of a thermostat and the substitution of windows. The second one includes the refurbishment of opaque surfaces (external walls and roof) and the thermostat. The final one considers a better Heating, Ventilating and Air Conditioning (HVAC) management (i.e. peak shaving). In the end, it was possible to obtain as a result the total annual simulated energy consumption for each scenario and the relative percentage of saved energy, calculated through the comparison of the energy consumption before and after the application of the strategy. Finally, a Cost Benefit Analysis (CBA) was integrated, in order to show the costs related to each strategy using Return on Investment (ROI), Net Present Value (NPV) and Internal Rate of Return (IRR). This way it was possible to check the efficiency of each strategy, in both energy saving and economic terms.

Following the DIMMER methodology, it is possible to go beyond the district model itself; the DIM is enriched of a great amount of data managed through the middleware, useful for a considerable number of interoperability tests.

## The DIMMER Middleware

### Middleware for District Information Modelling

A virtual model for the district should overcome several challenges. For instance, the seamless integration of the different data sources which compose the district model requires to deal with the different standards used by each data source. Furthermore, the different components may be provided by independent players, which are usually distributed in several locations. Each player may contribute to the enrichment of the district model by deploying an independent software service. Therefore, a comprehensive district software infrastructure should be designed, to tackle both the technology heterogeneity and the distributed nature of such a district model.

The proposed software infrastructure is based on the LinkSmart OpenSource Middleware (Linksmart), adopting and extending it to address the requirements of a Smart City context. In particular, it needs to: i) correlate different models for buildings (BIM), district energy systems (SIM) and georeferenced district information (GIS) to create the DIM; ii) model real-world Internet of Things (IoT) devices and ICT (Information and Communication technology) systems; iii) correlating data coming from IoT devices with the DIM and iv) exposing their data via common application protocols. *Figure 3* shows the architectural schema of the proposed software infrastructure. It consists of three layers: i) IoT Devices and Technologies Integration layer, ii) Services layer and iii) Applications layer. The rest of this section describes each layer in more detail.

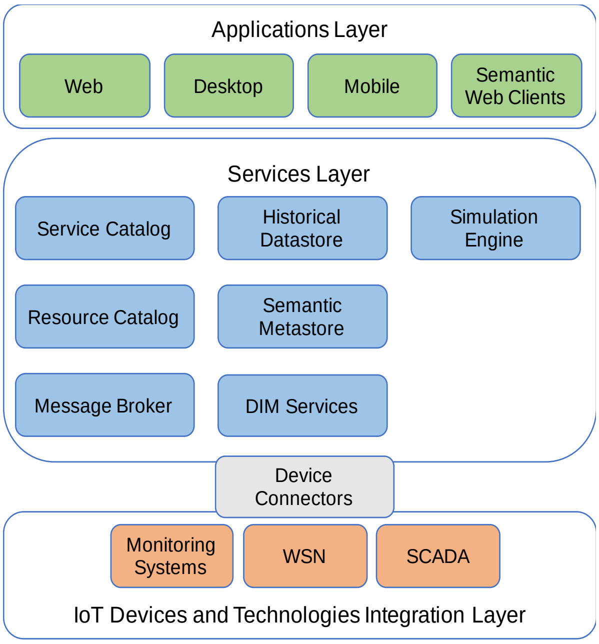

*Figure 3: Architectural schema for the proposed IoT software infrastructure for Energy Management and Simulation*

### IoT Devices and Technologies Integration layer

This layer, the lower in *Figure 3*, oversees integrating heterogeneous hardware technologies by abstracting their features into Web Services. Hence, it acts as a bridge between the rest of the platform and the underlying technology, translating whatever kind of language the low-level technology speaks into Web Services. In this layer, we integrated different standards for devices to monitor and manage buildings and energy distribution networks, such as EnOcean, Spirit and SCADA.

### Services layer

This layer is the core of our platform. It creates the virtual model of the district, (aka DIM) and correlates it with (near-) real-time information retrieved from the IoT devices imployed in the real district. Hence, the platform also provides features to access and manage IoT devices exploiting a Web Service approach. Finally, it offers features for simulating control policies to reduce energy consumption, again from a district viewpoint. The main components of this layer are described in the following paragraphs.

*Service Catalog* and *Resource Catalog* provide information respectively about services and endpoints for IoT devices available in the platform. They are the entry points for applications, used to discover services and resources in the network. *Message Broker* provides (near-) real-time asynchronous communication for the different components of the infrastructure, by means of the MQTT (Message Queue Telemetry Transport) (MQTT, 2015) communication protocol. The *Historical Datastor*e provides Web Services to access historical sensor data in the proposed platform. In its core, it implements interfaces to integrate time-series databases (e.g. InfluxDB), designed to manage Big Data. In addition, the *Historical Datastor*e provides optional aggregation functionalities that can be used to down-sample high-frequency sensor measurements and calculate basic aggregates on them. *Semantic Metastore* enables the use of Semantic Web technologies to annotate and interlink integrated data-sources and query them using the semantic attributes. Such annotations can be used for describing higher-level services and applications, as well as to model real-world entities they operate with that are not directly managed by the platform.

*DIM Services* creates the virtual parametric district model and provides features to access its information. A DIM is composed by different entities. In particular, it is possible to define three specific data sources, which are represented using relational databases, and can be integrated to get a comprehensive view of a district:

- ***Building Information Models*** (BIM) are parametric 3-Dimensional models, where each model describes a building - both structurally and semantically;
- ***Geographical Information Systems*** (GIS) map the geographical location and topology of district entities, such as district buildings or energy distribution networks: GIS provides data management and modelling for advanced cartography;
- ***System Information Models*** (SIM) describe size and structure of energy distribution networks.

DIM Services is based on Web Services approach to allow a distributed deployment of these data-sources. The use of Web Services provides a uniform interface to each component of the system. In detail, the DIM Services is shown in *Figure 4*. From a logical viewpoint, each component in DIM services consists of two independent sub-layers: i) Data layer and ii) Interface layer. In the following, the structure of the BIM Service Provider is presented, which is easily extended to GIS and SIM Service Providers. The Data layer is a set of several databases, where each database represents a building in the district. The databases are managed by using a relational DataBase Management System (DBMS), which is able to store the internal representation of the BIM models. The Interface layer provides Web Service interface to the underlying databases. It interacts with the Data layer by using SQL queries and preparing JSON results. Furthermore, it also provides building resources, such as proprietary (Revit files) and public BIM standards, such as IFC and gbXML.

As depicted in *Figure* 4 within the DIM needs information also from GIS and SIM. Both these data-sources need a Web Service interface to be integrated into DIM Services by means of DIM context layer. Both the GIS and the SIM Service provider return JavaScript Object Notation (JSON) results through their Web Services. DIM Context layer is the last sub-component of DIM Services that is on top of each Service provider. It is the main interface to district information. This component creates the virtual parametric model of the district that can be queried as a whole by client applications. It acts as a translator from the district context (district-based queries) to a specific data-source context (e.g. building-based queries). Conversely, it also integrates back responses from the different *Service Providers* to a single response. Moreover, it is able to compose complex queries, which may span different information domains. For instance, by querying both the *BIM* and the *GIS Service*

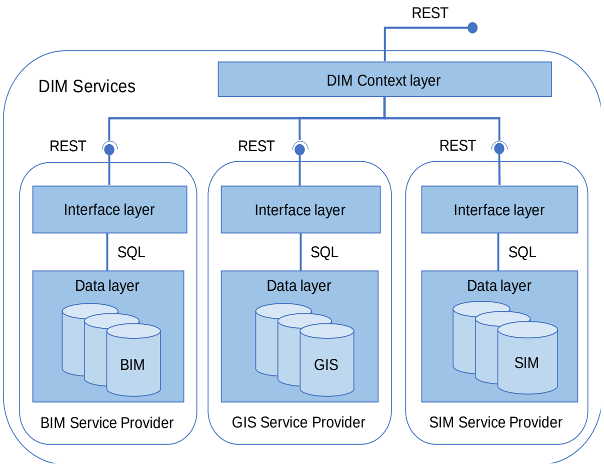

*Figure 4: DIM Service schema*

*Providers*, it can retrieves information about buildings composed by a specific number of stories.

*Simulation engine* is a specific component of the proposed platform used to help in developing new control policies and to perform energy simulations for the different energy flows in the district (e.g. electrical and heating) in a district environment. It consists of a Web Service interface that provides a standard entry-point to the district simulator. To develop and run control policies, it is able to retrieve information from all the other platform components. For instance, simulations can retrieve data from both DIM and historical or information collected (near-) real-time from the IoT devices.

### Applications Layer

The *Applications Layer* (the highest layer in *Figure 3*) provides a set of Application Program Interfaces (APIs) and tools to develop applications to manage data coming from the lower layers of the platform. Example of applications are the Benchmarking Tool and the *Web-GIS* described in the sections below.

## The Benchmarking Tool framework

The Benchmarking Tool is a web application which provides modelling and data visualization. The tool compares the energy performance of a selected building in different heating seasons and/or against other similar buildings (respecting the privacy) as well as assesses possible scenarios for building improvements. The Benchmarking Tool is targeting mainly to the Building Managers as well as Estate Managers both in public and private domains. The Benchmarking Tool innovation consists of the capability of evaluating how the district is influenced by single building and vice versa. Innovative aspect is provided also by the possibility to compare the building energy behavior (in terms of energy consumptions) against "a virtual building" representing the average behaviors of similar buildings in the district for privacy reasons. Last but not least, the Benchmarking Tool provides a web-based viewer for the visualization of IFC/BIM models based on WebGL technologies. In this context, the Benchmarking Tool provides a complete vision of the district through two services in *Figure* :

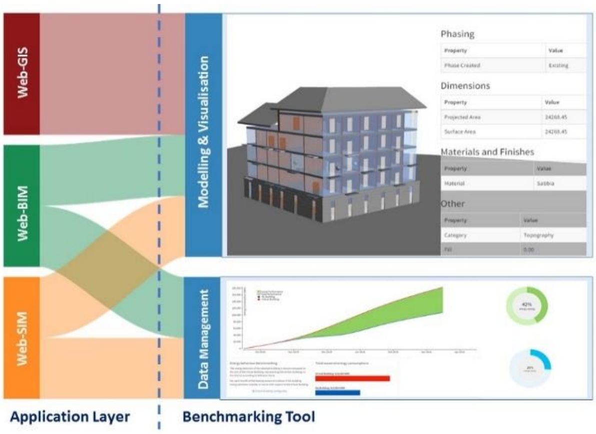

Figure 5: The Benchmarking Tool Framework

- Modelling and Visualization: this solution integrates district information aggregating the following DIM entities: i) GIS data at the district level such as buildings, networks and topology; ii) BIM data to model the building and understand its energy behavior, and iii) SIM data from real time sensors at network and building level such as district heating/ power networks, energetic and environmental;
- Data Management: by mean of the Virtual Building, defined at district level, this service visualizes the district information through real time data. This service aggregates the following DIM entities: i) BIM data to modelling the building and understand its energy behavior, and ii) SIM data from real time sensors at network and building level.

The data management and modelling and visualization services provide an appropriate user experience by offering nearly real-time visualization and asynchronous notifications on changes in the real-world entities, acquiring data from (physical and virtual) sensors, as well as other relevant data sources, processing to calculate different properties of context models and to deliver the information to the users.

In this context, DIM information is provided by the interaction among different datasets and domains (GIS, BIM and SIM) through the middleware. The GIS layer defines the spatial boundaries of a district (e.g. all buildings of a district); the BIM layer defines the physical entities of buildings (e.g. all buildings with a specific floor area and a target thermal transmittance), and the SIM layer defines the virtual entities (e.g. all buildings with an energy consumption below a specific set point). The Virtual Building is defined as the intersection of the BIM, GIS and SIM datasets, on which the user can apply a filter on demand (*Figure 6*). From a more technical point of view, to define the Virtual Building, the tool performs a set of REST queries to the BIM, GIS and SIM web services, retrieving the list of building identification that meets the characteristics selected by the user. The intersection of these lists defines the Virtual Building and the context (DIM) in which the selected building has to be assessed. Indeed, by including or excluding defined ranges of values related to the single criteria considered for the definition of similar buildings in the district, the Virtual Building will respectively comprise more or less buildings considered similar to the selected one, according to the wish of the user of having a less or

Figure 6: Virtual Building Configurator

more precise reference benchmark (*Figure 6*).

## Results

### Data visualization

The Benchmarking Tool was designed to follow a top-down approach, starting from a district level and going into further detail at building level. Indeed, from the initial page of the tool, the user, in the context of a selected district (as in the case of one of the pilot cities), can select a building in order to perform energy comparisons and simulation as benchmark for investigating the energy behavior of the building itself.

The added value provided by the tool is related to the ability to combine the reference calculation used for cross-country comparison defined in literature (e.g. HDD, ISO, building energy signature) and real data coming from the sensors deployed on the field (e.g. energy consumption, indoor/outdoor temperature, building information modelling). The aim is to enable a realistic assessment of energy and heating costs savings, keeping into account privacy issues. The result is a benchmarking tool in which the target building (virtual building) is defined taking into account the boundary conditions (e.g. location, temperature, householder behavior) of the reference building.

The Benchmarking Tool was conceived to provide the following main functionalities in *Figure 7*.

**Visualization and deep navigation of the Building Information Model (Yellow icon)**, showing the IFC/BIM model of the selected building the user may visit the building page where the tool provides an overview of the main characteristics of the selected building. *Figure 8* shows: (A) architectural data structured by levels; (B) building 3D view and query building object; (C) architectural properties (area, volume); (D) general data (construction period, use/destination, energy supplier etc.); and (E) real-time temperature collected from the external sensors located on the building balcony (green object). This functionality has been developed on the BIMserver platform.

**Energy Consumptions Benchmarking: Virtual Building vs. My Building (Blue icon)**, showing the comparison of the energy consumptions of a selected building with those of a Virtual Building representing similar buildings in the district.

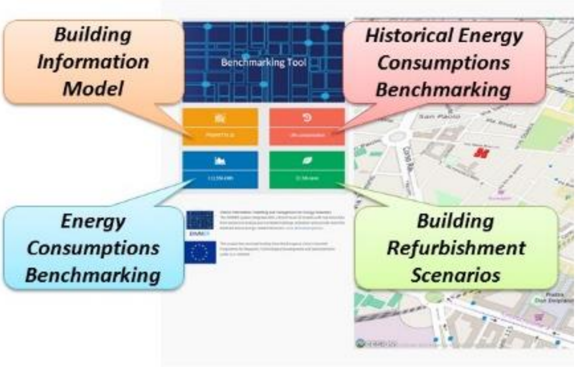

*Figure 7: Benchmarking Tool Core Functionalities*

*Figure 8: Visualization and deep navigation of BIM*

The energy behavior of the selected building is shown compared to the one of the Virtual Building, representing the similar buildings in the district according to defined criteria in *Figure 8* section A. Per each month of the heating season the chart shows the total energy consumed by the building selected (blue line) and virtual building (red line). If the building energy behavior is better respect to the Virtual Building the area of chart between the two curves is green otherwise it is red. The chart in *Figure 8* section B provides at a glance an overview on the total seasonal energy consumption of the building selected (blue bar) and virtual building (red bar). Finally, the Chart in *Figure 8* section C provides a percentage of energy saving, if the building energy behavior is better respect to the Virtual Building, otherwise the percentage is on consumed energy, if the building energy behavior is worst with respect to the Virtual Building.

For sake of clarity, the following example is provided as potential scenario of use of this functionality. Let's consider a building manager who receives the energy consumption bill. The total energy consumed (kWh) and the total amount (€) reported in the bill are not enough to understand the building energy behavior. The Benchmarking Tool supports the building manager to understand the building energy behavior, in particular the tool shows if the energy consumptions of a selected building are less, more or the same with respect to similar buildings in the same district. By using the Virtual Building Configurator (*Figure 6*), the building manager defines the Virtual Building by setting the similarity boundaries among the district building. Once defined the Virtual Building target, the building manager is able to compare if the energy behavior of his building is better respect to the Virtual Building.

**Historical Energy Consumptions Benchmarking (Red icon)**, showing the energy consumption of a selected building over time *Figure 9*, in particular: (A) over the last 3 heating seasons; and (B) normalized to Degree Days [DD]. The normalisation is an added value provided by the tool. The chart in *Figure 9* B shows an abnormal consumption related to the heating season 2014-2015 (orange bar), in which the total energy consumed is less than the previous season

*Figure 9: Historical Energy Consumptions Benchmarking*

(2013-2014) but the normalized value is greater. This means that in the winter season 2014-2015 the building consumed more energy respect to the previous one with the same climatic conditions.

**Building Refurbishment Scenarios (Green icon)**, simulating different refurbishment options (on windows/roof/façade *Figure 10* section A). The simulation evaluates different refurbishment options towards the improvement of building energy behavior and at the same time it calculates money and $CO_2$ savings (*Figure 10* sections B and C). These energy simulations should be considered the starting point for the renovation of the building. The simulation is performed by evaluating the delta Q (energy consumption) among the actual and new technologies. In particular, the ISO 13790:2008 and the heating degree-day method have been applied for the assessment of the winter season energy use. The simulation result takes into account the benefits obtained with the best transmission coefficient of the new technologies installed without changing the current climatic conditions.

By using this functionality, the building manager is able to simulate different solutions of building refurbishment, identify the best strategy for energy savings and potentially put it into practice towards energy consumption reduction.

## The advantages of interoperability

In the Benchmarking Tool the district model must satisfy the following constraints: (i) the use of underlying hardware (e.g. sensors) must be transparent from the user's point-of-view; (ii) each data source must be able to be registered into the system without needing to restart the whole infrastructure; (iii) the system must communicate by means of shared open protocols; (iv) the system must handle the data integration; (v) the data format must be open and independent from data source. Interoperability is achieved by mapping parts of each participating application's internal data structure to a universal data model and vice versa. In the district management, the distributed infrastructure integrates and interconnects different models and data sources, and delivers information by means of web-based technologies.

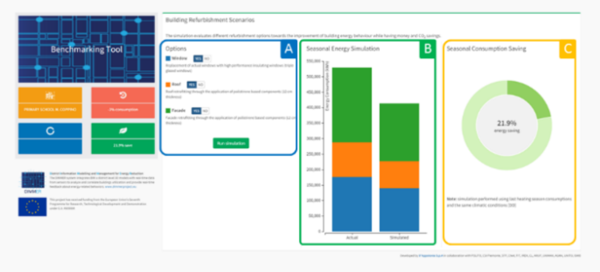

*Figure 10: Building Refurbishment Scenario*

Having regard to the complexity, difference and the amount of data to manage, the Benchmarking Tool has been designed and developed to retrieve and process data on demand from middleware without a local replication of data. This complex system that provides information about different environments (e.g., energy, GIS, sensor, building, district etc.) has to face to the exponential growth in complexity when integrating increasing numbers of resources that need to exchange information; such a situation has driven the requirement for a common format that covers all the areas of data exchanged, for example, in the energy and ICT domains. In addition, going beyond the simple data format, the shared information model must provide explicit rules enabling the data items that populate this model to be interpreted without ambiguity. Semantic models address the needs of interoperability by creating a shared understanding of different domains and a shared method of representing data and their meaning. The scope of the Semantic Metastore implemented in the Middleware Service Layer is two-fold: from one side, it aims to "integrate" the complex district environment from the district elements (such as Buildings, energy distribution networks, devices, etc.) and energy point of view, and on the other side, this model supports the ICT interoperability among all the software systems and devices present in the domain enabling the proper communication of the information with the aim of improving the building energy behavior towards the improvement of energy efficiency at district level. The semantic framework defined has based on a global ontology that integrates the local ontologies specific for the domains of interest of the actors: the global ontology acts as intersection of all these local ontologies and it is used to facilitate reusing of concepts and mapping of local ontologies. A global ontology can be also understood as a neutral reference which results from the union of all local ontologies (Brizzi, 2016).

## Interdisciplinary process

The interdisciplinary process is one of the key point of the BIM methodology. The data sharing is possible through the interoperability, which offers the possibility to share geometric and alphanumeric information through an international standard language. Interoperability is not only a piece of the "BIM jigsaw", but it is a prerequisite for the development of the BIM methodology. However, interactions and information exchange between systems are still in a primary stage and users do frequently encounter problems when they want to collaborate with other actors from different companies who use other systems. Additionally, there is still a lack of tools that do support a collaborative workflow in performance based design and exploit all the capabilities that BIM grants (Pruvost, 2016).

Within this process, the use of ICTs is essential in order to optimize the data flow. The platform is the repository where all relevant data is collected and extracted on the basis of the users' needs with different kinds of format (*Figure 11*). This way it is possible to manage the great amount of data concerning a city, without visualizing useless data when not necessary.

Several researches have been carried out in order to realize the data conversion among systems. The openBIM-based energy analysis software (OBES) was developed as a BIM-based EPA (Energy Performance Assessment) support system that provides IFC data validation, automatic conversion from IFC to IDF (Inspire Data File), to maximize the interoperability between these file formats. For example, the support system reads the material code in the BIM object, loads the assigned thermal information on the material code in the library, and inputs that information as a material parameter in the IDF data. Future research should deepen a methodology to exchange HVAC information to realize the automatic transformation of BIM data into EPA information (Choi, 2016).

For this reason, interdisciplinarity is one of the greatest advantages of BIM, because by adopting this methodology it is possible to integrate several disciplines.

## Conclusion

In the last years, interoperability has been considered the right way for sharing information in the building process among different users, although it is not yet error free.

In a district context, where inhabitants are included in the development process, data collection was one of the most demanding phases; this is due to the data availability, linked to several privacy issues.

However, the DIMMER system has proved to be efficient in sharing data between different data-sources at different scales; for this reason, it is a viable approach to develop smart cities/districts, merging the needs of several users. The DIMMER middleware was able to collect heterogeneous data, highlighting the advantages provided by ICTs for the building industry. The creation of the Benchmarking Tool, as a dashboard that exposes data, is useful to modify settings in real-time for data visualization.

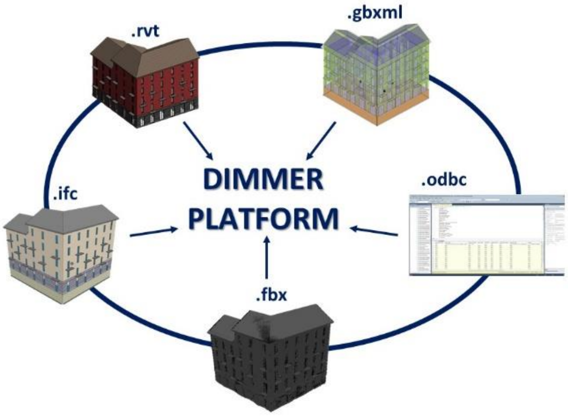

*Figure 11: File formats dispatched by the Middleware*

This work demonstrates that the use of DIM and the process followed for data visualization is a key element that goes beyond the 3D city modelling itself, enhancing the value of interoperability and interdisciplinarity and improving the citizens' awareness about energy consumption.

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