RÉPENER's Linked Dataset

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Abstract. The dataset presented in this paper constitutes one of the outcomes of RÉPENER- a research project, co-funded by the Spanish RDI plan. It contains integrated information of the Spanish territory, regarding energy certification, building monitoring, and geographical data. The integration has been carried out by means of semantic technologies. The following of the Linked Data principles helps to guarantee standard methods of accessing the data as well as to connect data to the existing dataset on the Web of Data. The dataset is a Knowledge base for end-users. It has a clear objective of providing information that stakeholders need for improving energy efficiency of buildings, influencing, thus, their respective decision-making areas.

Keywords: energy efficiency, energy certification, data integration process, ontology, Linked Data

1. Introduction

Nowadays, the improvement of the energy-efficient of new and existing buildings is a key issue in the European Union in terms of policy. There is a clear goal of reducing carbon emissions and energy consumptions. Designing and building more efficient buildings become necessary to have a better knowledge of the relationship between design and performance and between the design objectives and the actual performance of the building. At the same time, improving existing buildings implies knowing their actual performance; and therefore, taking steps toward optimization. This requires having access to energy information at the different stages of the building life-cycle –from design, to construction, and operation– and not in separated sources. In fact, having access to suitable and condensed information become crucial for stakeholders as it allows them to make more informed decisions, to increase energy efficiency. Having this information may lead, for example, to best practices when designing new buildings or when refurbishing existing buildings, or when tuning building energy management systems.

Therefore, the dataset that is going to be presented in this paper, may be considered useful as it is precisely a knowledge base for end-users. The dataset is one of the outcomes of the RÉPENER research project, a detailed description of the system can be found in Madrazo [1]. RÉPENER's dataset contains energy data from different sources including the physical characteristics of a building; both passive and active; environmental features, use profiles and consumption values. In the dataset, the energy data is modelled as Linked Open Data which is exploited by RÉPENER's services as well as by the ones provided by third parties.

This paper describes the process of creation of RÉPENER's dataset using Linked Data standards, techniques and technologies. It is structured as follows. Section 2 describes the main features of the data sources. Section 3 presents the data modelling including ontology creation, data transformation, data linking and data publishing. Section 4 describes the current use of the dataset including the services

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which utilize the dataset itself. Section 5 presents the related work relevant to the domain. Finally, in section 6 conclusions are summarized.

2. RÉPENER's dataset

The goal of the dataset is to collect data from the different stages of the building life-cycle for analysis. The dataset is the result of the integration of three data sources, encompassing energy certificates, building descriptions, simulations results, energy monitoring, and environmental data.

Energy certification of buildings, collected by public administrations, specifically by the Catalan Energy Institute (ICAEN)[1], is the first and main source of data. The data comprises energy certifications and their simulated performance during several stages of the building life-cycle including design and refurbishment. ICAEN provides data in a single spreadsheet in which each row is an energy certificate of a specific building. Each energy certification contains the energy rating of the building, energy consumptions, types of the HVAC (Heating, ventilation, and air conditioning) systems, and geometric features such as the built surface or the compactness (a ratio between surface of a building and its volume). Besides, the ICAEN owns more than 1800 energy certifications, 202 have been included in the dataset because of its simulation details. Since some relevant attributes, such as consumptions and emissions, were empty; approximation values have been calculated according to the studies of energy consumption of the building sector [2], to the standard values of ISO [3] and taking into account the Spanish regulations.

The second source of data contains monitoring data of buildings. It is provided by Leako[2], a Basque company dedicated to installation, distribution and HVAC control, which maintains a Paradox database of energy consumption data (for example, thermal consumption for air and water heating, and water consumption) and indoor conditions (for example, air temperature) for several buildings.

It was thought to use GeoLinked dataset (.es)[3], in the first place, but due to its lack of detailed data regarding cities such as population, surface, or elevation; the Spanish gazetteer has been selected instead. The Spanish gazetteer is provided by the Geographical Information National Institute (CNIG)[4]. It is a Microsoft Access database which stores the populated places of the Spanish territory including geographical data for each record such as population, areas, elevation, or Universal Transverse Mercator (UTM) coordinate. This source does not include a climate zone classification for places which is relevant for the services of RÉPENER as described in section 4. For this reason, we have estimated the climate zone for each populated place based on the Spanish Building Code (CTE) which provides distribution of climate zones per capital province.

3. Dataset modelling

RÉPENER's ontology has been used to specify the data schemas of individual sources mentioned above in a single model. A comprehensive description of the ontology design process is provided by Nemirovskij [4]. The domain of the ontology is the building energy performance and it inherits many elements from energy standards such as the energy certification of buildings defined by the DATAMINE project [5] and the ISO CEN standards that follow the European Directive 2002/91/EC (For example, ISO 13790:2008). These standards cover some areas of the ontology, in its core. They are defined as follows:

- General project data: Project descriptions, collecting its generic characteristics such as location, use, project execution data, and site description.
- Performance: Indicators regarding energy use such as energy demands or consumption of different energy carriers, CO_2 emissions and indoor conditions such as temperature and humidity.
- Building properties: Parameters which express geometric characteristics, construction systems and building services.
- Outdoor environment: Climate characteristics and conditions of the physical environment such as outdoor temperature, wind speed and direction, and solar radiation.
- Operation: Parameters regarding the usage and management of the building and its facilities for maintaining comfort levels such as solar protection or thermostat regulation.

[1] http://www.gencat.cat/icaen
[2] http://www.leako.com
[3] http://geo.linkeddata.es
[4] http://www.cnig.es

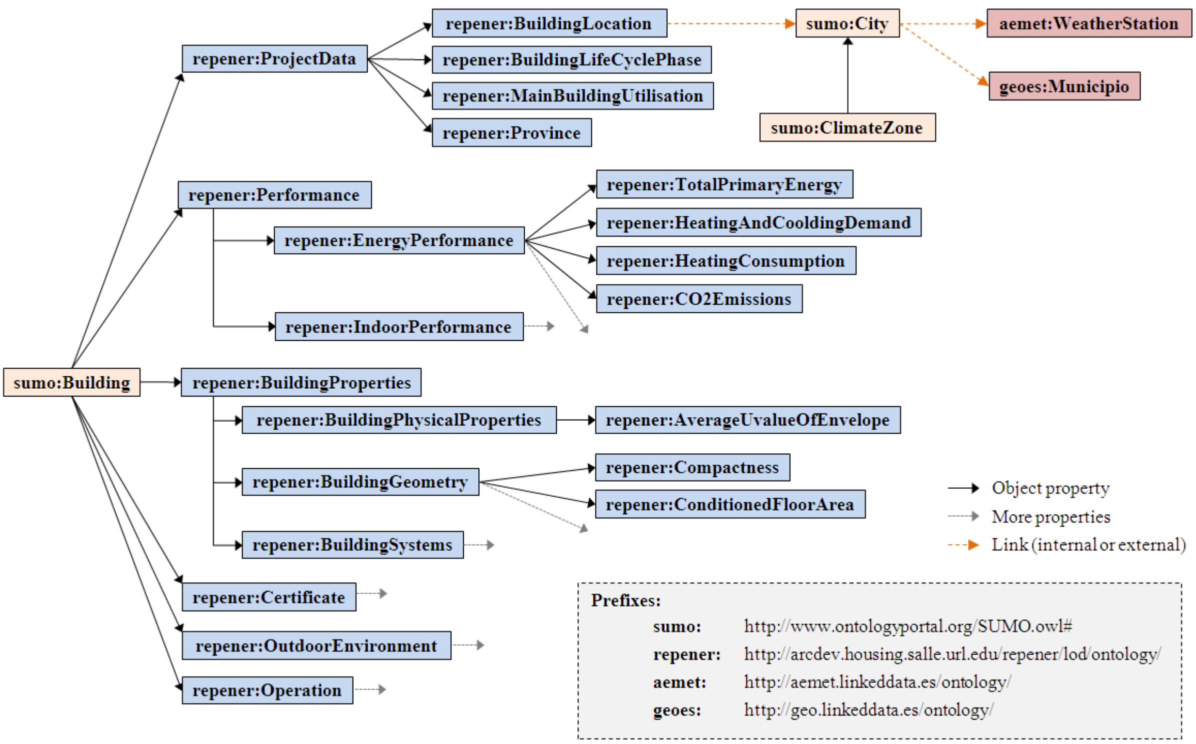

Fig. 1. RÉPENER's ontology excerpt.

– Certification: Indicators to qualify a building based on performance such as the energy efficiency rating according to a conventional Spanish scale as (A, B, C and so on). It also includes the certification-process methodology.

RÉPENER's ontology uses the upper-ontology, the Suggested Upper Merged Ontology (SUMO) in [6] that can be applied for reasoning and inference purposes, and contains related-domain units of measure such as meter, watt, or joule. The ontology is coded in OWL $\mathit{DL\text{-}Lite}_A$ formalism which outperforms –in terms of computability in specifics cases such as conjunctive queries of large data volumes– the conventional OWL language. The ontology embraces 71 classes and 100 properties in $\mathit{DL\text{-}Lite}_A$ style, implemented with 858 axioms. Figure 1 shows a small part of the ontology including the links to external datasets. Data transformation

The dataset has been created through an ETL (Extract, Transform and Load), a process which converts the sources to RDF according to RÉPENER's ontology. The components of the process can be found in Figure 2. The challenge of the process resides in the heterogeneity of the sources –spreadsheets, Paradox database, and Microsoft Access– with a direct impact on the extract phase. D2RQ mapping language, proposed by Bizer and Cyganiak [7], and their dump-rdf[5] tool have been selected to implement the transformation phase. Finally, the load phase implies uploading RDF dumps, generated for each source, on the Virtuoso server[6]. The implementation of the three phases is described below:

– Extract. Paradox is an obsolete database which does not offer interfaces to be used by present tools. For this reason, a script has been implemented to move the contents of the Paradox files to a MySQL database which is reachable by D2R Server. In addition, the data extracted from Paradox files have been aggregated from hourly to monthly values since its usage is foreseen in a kind analysis which does not require low level of data aggregation. The ICAEN spreadsheet has been also migrated to a MySQL database.
– Transform. This phase consists on creating a D2RQ mapping file for each source. Mappings have been carried out by ontology engineers, translating each table and column of the databases to reflect the correct term and property from the ontology. Some classes, such as *repen-*

[5] http://d2rq.org/dump-rdf
[6] http://virtuoso.openlinksw.com

er:ConditionedFloorArea, require to relate themselves to units of measure. For this reason, and for accomplishing with this demand, additional mappings have been done. Furthermore, resources contain annotation properties such as *rdfs:label*. Finally, the values of the use of building (*repener:mainBuildingUtilisation*) have been converted –through D2RQ language constructs– to the classification provided by the DATAMINE project [5], an international domain reference. In this way, third-parties, from other countries, are able to understand the data.

– Load. Since all three sources have been mapped to the same ontology, their integration is directly merging the three RDF dumps. The resulting file has been uploaded to Virtuoso server.

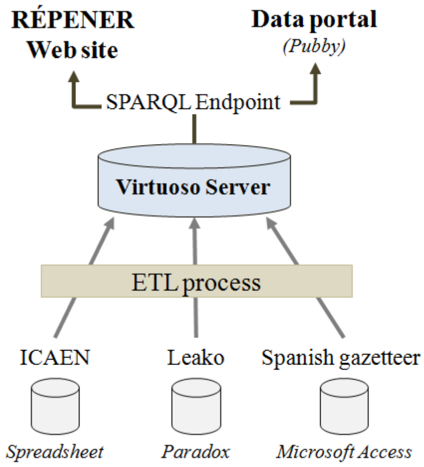

Fig. 2. Components of RÉPENER's dataset creation process.

3.1. URI design

All elements of the dataset have this base URI: *http://arcdev.housing.salle.url.edu/repener/lod/*. The concepts and properties of RÉPENER's ontology can be found under this URI: *http://arcdev.housing.salle.url.edu/repener/lod//ontology/{class|property}*. Each concept has some annotation properties such as *rdfs:label*, *rdfs:comment*, *repener:reference*, and *repener:author*. Comment and reference properties are important because of their usage on RÉPENER's website[7], helping users to understand the data they are visualizing, and the energy standard, data is based on. An example of a concept is *repener:CO2emissions* (see *http://arcdev.housing.salle.url.edu/repener/lod/page/ontology/CO2emissions*).

Regarding the resources, the URI pattern, selected to identify the instances, uses pluralized class names and an identifier following Patterned URIs solution stated by Dodds and Davis [8]. This pattern was selected since people are able to read it and it is easily generated from a database where identifiers (for example primary keys) are always present. Furthermore, adding a class name to the base URI mitigates the problem of generating different individuals with the same identifier but different class. Generally, the Natural Keys pattern [8] has been applied to model the URI identifiers. In some cases, the identifier has been created following URL Slug pattern [8] to ease dataset exploration (For example, *http://arcdev.housing.salle.url.edu/repener/lod/resource/city/Barcelona*). In this case, a text property of the resource has been converted using the urify[8] pattern which applies a URL encoding and converts the spaces to underscores.

3.2. Data linking

The ETL process described above, in the *3.1 Data transformation* section, has carried out the first step of the data integration process. The second step is to interconnect the data from the different sources for providing combined access to data that has been originated from different provenance and domains. We have adopted two strategies to connect the data sources.

– The same URI patterns in different data sources have been used to model the same type of resources. This can be done if the sources contain the same values for describing the data. For example, *repener:ClimateZone* resources are generated by both, the ICAEN source and the Spanish gazetteer. In both sources, the climate zones are indentified with a character and a number, based on the Spanish Building Code. For instance, a climate zone resource such as *C2* (see *http://arcdev.housing.salle.url.edu/repener/lod/page/climatezone/C2*) connects both sources through *repener:hasCity* and *repener:hasBuilding* properties.

– Internal links between the data has been generated, when the strategy previously described could not be applied. The SILK framework, described in Volz et al. [9], has been used to con-

[7] http://arcdev.housing.salle.url.edu/repener

[8] http://d2rq.org/d2rq-language#dfn-uri-pattern

nect the building location resources (from ICAEN's and Leako's sources) with the populated places (from the Spanish gazetteer) using *owl:sameAs* relations.

The data sources also have been connected to external datasets, such as Aemet meteorological dataset[9] and GeoLinked Data (.es), enriching the Web of Data with Spanish geospatial data. In total, 783 links have been established with Aemet dataset and 7160 links with GeoLinked data.

The Aemet dataset provides climate data from the Spanish Meteorological Office, gathered from 204 weather stations across Spain. This connection is relevant since the outdoor environmental properties of the buildings can be enhanced with the data monitored by the Aemet's weather stations. The SILK framework has been configured to discover *repener:closestStation* links between *repener:City* and *aemet:WeatherStation* instances, using a geographical distance measure with a maximum distance of 50 kilometres between the city and the station.

GeoLinked dataset publishes diverse information sources of the National Geographic Institute of Spain (IGN-E) and the National Statistic Institute in Spain (INE), among others [10]. Some of the data in this dataset complements the one of RÉPENER. This is an advantage for the user since different but complementary information of the same domain is accessible for him. The connection to the GeoLinked dataset is significant since the presence of geographical relations between other entities. These are the cases of capital of province (*geoes:esCapitalDe*) [10] and part of a region (*geoes:formaParteDe*) [11]. Furthermore, this dataset already contains links to GADM dataset which provides different geometry descriptions of a spatial element for different scales. In this case, an aggregation of a character-based distance measure (*Levenshtein*) and a geographical distance have been designed to generate *owl:sameAs* links between *repener:City* and *geoes:Municipio* instances. The geographical distance is useful to avoid false positives when cities with the same name are located in different areas.

3.3. Data publishing

Data is accessible through the SPARQL endpoint provided by the Virtuoso server, used by RÉPENER's data portal and by RÉPENER's end-user services. The data portal has been implemented with the Pubby[12] tool following the Linked Data principles. The Pubby instance serves both, ontology and data. For example, the class *repener:TotalPrimaryEnergy* can be explored following this URL: *http://arcdev.housing.salle.url.edu/repener/lod/page/ontology/TotalPrimaryEnergy*. Representative resources of the dataset are buildings, for instance, *http://arcdev.housing.salle.url.edu/repener/lod/page/building/001B00126908P0*.

Table 1 provides a summary of the main features of the dataset.

Table 1

Overview of the dataset features

VoID file	http://arcdev.housing.salle.url.edu/repener/void/repener.ttl
Homepage	http://arcdev.housing.salle.url.edu/repener/
Base URI for instances	http://arcdev.housing.salle.url.edu/repener/lod/resource/
SPARQL endpoint	http://arcdev.housing.salle.url.edu/repener/sparql
Graph name	http://arcdev.housing.salle.url.edu/repener/lod
Number of triples	150297
Number of distinct subjects	18962
Number of distinct objects	26097
owl:sameAs links	7239
repener:closestStation links	783

4. Dataset exploitation

As stated in the introduction, this dataset gathers data from different phases of the building life-cycle. In this way, stakeholders –from architects and energy consultants, to building and facility managers and consumers– will obtain the information they need to contribute with the improvement of the buildings' energy efficiency, in their respective decision making realms. For instance, energy specialists would be able to implement energy performance benchmarking on the energy information systems to answer customized demands in real-time. Moreover, learning from examples of efficient buildings could be facilitated by the information in the system: design patterns and building systems could be identified, based on the analysis between design and performance. The end-

[9] http://aemet.linkeddata.es/
[10] http://geo.linkeddata.es/ontology/esCapitalDe
[11] http://geo.linkeddata.es/ontology/formaParteDe
[12] http://www4.wiwiss.fu-berlin.de/pubby/

user services of RÉPENER, thus, have been envisaged to fulfil the needs of the stakeholders.

4.1. Examples of energy efficient buildings

Users of this service wish to explore cases of energy-efficient buildings which meet a particular design criteria. Firstly, users inform about the city or postal code where the buildings should be located. According to the provided information, the climate zone is automatically set. The main use of the building (For example, Residential or Office) has to be also specified. Afterwards, users tell about the energy uses and performance indicators that are important to their context. A list of the buildings which meet the inputs from the users is retrieved from the dataset by submitting SPARQL queries to the endpoint. The energy-efficient buildings are visualized in a table showing the different performance indicators. It can be explored also graphically, in a heat map implemented on top of Google Maps. Once a building is selected, a report of its main attributes is shown to the users. The report is structured according to the main taxonomy of the RÉPENER's ontology.

4.2. Performance benchmarks

This service benchmarks the main performance indicators of the dataset of buildings before and after its refurbishment. The indicators included are: heating consumption (*repener:HeatingConsumption*), CO_2 emissions (*repener:CO2emissions*), total primary energy (*repener:TotalPrimaryEnergy*), heating demand (*repener:HeatingDemand*), among others. Users provide the location –city name or postal code– and a main use to filter buildings included in the benchmark. The benchmark of the performance indicators are shown to the user in two separated columns, one for energy efficient building and other for the not efficient buildings. Two values are displayed for each indicator, before and after the renovation of the building. In addition, and in a way of providing more information, its percentage of improvement is shown. In this way, users can know the common values of energy-efficient buildings and compare them with the ones that correspond to non-efficient buildings. Users are also able to see how much of improvement they would have for each performance indicator.

4.3. Energy efficient design patterns

The goal of this service is to identify the correlations between the design variables and the energy performance of energy-efficient buildings. The service recognizes the common properties of the buildings such as prevalent orientation of the window area (*repener:PrevalentOrientationOfWindowArea*), energy carrier of first heat generator (*repener:EnergyCarrierOfFirstHeatGenerator*), solar contribution for hot water (*repener:SolarContributionForHotWater)*, or degree of centralisation of the first heat generator (*repener:DegreeOfCentralisationOfFirstHeatGenerator)*. This kind of analysis helps to define which design options would reduce the energy consumption in the case of refurbishment, constituting a clear advantage for the user, giving him fundamental information. This service is still under development.

4.4. RÉPENER's website

RÉPENER's website collects these generic end-user services which can be exploited by different stakeholders who will obtain the appropriate data according to their domain of knowledge. For instance, a facility manager will see data regarding building management systems. For example, setpoint temperature (*repener:TypicalCoolingSetPointTemperature*), and occupation ratios (*repener:PresenceTimePerDay*). On the contrary, an architect will have design properties such as U-value of the envelope (*repener:AverageUvalueOfEnvelope*) or compactness (*repener:Compactness*). This feature is another clear advantage for the end-user, as he will have the exact needed information. The website accesses RÉPENER's dataset endpoint directly to retrieve the data. Furthermore, the labels and tooltip descriptions are retrieved from RÉPENER's ontology with SPARQL queries. The website is close to reach its completion; in the following weeks all services are going to be activated.

4.5. Example query

The dataset can be accessed directly, submitting SPARQL queries to the endpoint. The following query is an example of retrieving building's properties from the dataset:

```
prefix repener:
<http://arcdev.housing.salle.url.edu/repener/lod/ontology/>
prefix geo: <http://www.w3.org/2003/01/geo/wgs84_pos#>
prefix sumo: <http://www.ontologyportal.org/SUMO.owl#>
```

```
SELECT ?bid ?floorArea ?location ?lat ?long ?primaryen-
ergy ?station
FROM <http://arcdev.housing.salle.url.edu/repener/lod>
WHERE {
  []    repener:hasBuilding ?b;
        repener:value ?climatezone.
  FILTER (regex(?climatezone, "C2", "i")).
  ?b    a <http://www.ontologyportal.org/SUMO.owl#Building>;
        repener:hasProjectData [repener:hasBuildingLocation ?bl];
        repener:hasBuildingProperties
[repener:hasBuildingGeometry [repener:hasConditionedFloorArea
[repener:conditionedFloorAreaValue ?floorArea]]];
        sumo:hasPerformance [repener:hasEnergyPerfomance
[repener:hasTotalPrimaryEnergy
[ repener:totalPrimaryEnergyValue ?primaryenergy ]]];
        repener:buildingId ?bid.
  ?bl   repener:buildingLocationValue ?location;
        owl:sameAs ?c.
  ?c    geo:lat ?lat;
        geo:long ?long.
  OPTIONAL {
        ?c repener:closestStation ?station. }
   } order by ?primaryenergy
```

This query retrieves a list of buildings with some of their attributes. The properties are: the building ID, conditioned floor area, the location where the building is built, geographical coordinate of the location, the primary energy use of the building and the closest weather station using the links of the Aemet dataset. This last property is optional since not all of the building locations have a link to a weather station. The list is ordered by the primary energy use and filtered by the “C2” climate zone.

5. Related work

Recent projects such as Reegle [13] uses Linked Open Data technologies to access energy related data that has been obtained from open sources [11]. In the same line, the Open Energy Information (OpenEI)[14] online platform provides with free and open access to energy-related data, models, tools, and information which has been made available via Linked Open Data standards. With respect to these projects, the distinguished features of the dataset of RÉPENER, are the scale and source of the data. While Reegle and OpenEI platforms offer energy-related data at a country level –policies, regulations, energy production or renewable resource– RÉPENER’s dataset collects data for specific buildings; including physical characteristics, environmental characteristics, use profiles, and performance indicators; from different phases of the building life-cycle, assuring a more specific information for users.

6. Conclusions

In this paper we have presented a dataset which integrates data from different sources according to RÉPENER’s ontology. This ontology uses the SUMO ontology which is commonly used in the engineering community. One of the difficulties has been to integrate various sources which use three different storage systems, including an obsolete Paradox database. A data integration process, based on semantic technologies, helped to overcome it. RÉPENER’s dataset has been linked to Aemet and GeoLinked Data datasets which is relevant because they cover the entire Spanish territory, having complementary information with respect to RÉPENER’s dataset. This is a clear advantage for the user, since different information of the same domain is available for him. The generation of links and their relevance have been explained. The dataset has been published as Linked Data, enabling people to access it through a web interface –provided by Pubby– and letting services to retrieve data by issuing SPARQL queries at the dataset endpoint. This is the case of the end-user services embedded on RÉPENER’s website which exploits the contents of the dataset providing information of quality to stakeholders.

The main shortcoming of the dataset is its size which is relatively small (18962 entities at this moment) compared to the average size of the Linked Data cloud (591632)[15]. In spite of these figures, this dataset is bound to grow for two reasons. Firstly, an upload service will be deployed on the web site letting users to upload an energy simulation calculation of their buildings. The goal of this service is to compare the users’ data with the dataset’s benchmark, as well as to incorporate new cases to the dataset. The key parameters that are used to carry out the simulations, such as the simulation settings, are stored in the dataset for updating the benchmark. Secondly, a new law has been implemented regarding energy certification of existing buildings. Now, it is compulsory and not optional, to have a satisfactory energy certification. Within this new framework, these certifications are going to be collected by the ICAEN institute which is one of the main contributors of this dataset. Another negative point of the dataset is the lack of

[13] www.reegle.info

[14] www.openei.org

[15] http://stats.lod2.eu/stats

visibility of the results. This is because the project has been completed recently. The submission of an entry to the metadata repository for Open Data datasets, theDataHub.org, is foreseen.

In spite of these disadvantages, RÉPENER's dataset can contribute to the improvement energy-efficient buildings, giving the opportunity to end-users to make more informed decisions; supporting, at the same time, the current European Union policy.

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