Using a Smart City Ontology to support Personalised Exploration of Urban Data (Discussion Paper)

Devis Bianchini[1], Valeria De Antonellis[1], Massimiliano Garda[1], and Michele Melchiori[1]

University of Brescia, Dept. of Information Engineering
Via Branze 38, 25123 - Brescia (Italy)
devis.bianchini@unibs.it, valeria.deantonellis@unibs.it,
m.garda001@unibs.it, michele.melchiori@unibs.it

Abstract. During the latest years, Smart City projects aimed at driving local governments towards the strong use of technologies to support a higher quality of urban spaces and a better offering of public services. From an information viewpoint, this means enabling different categories of users, including citizens, Public Administration (PA), utility and energy providers, to access the large amounts of data in multiple, heterogeneous Smart City data sources, by adopting new tools and methods to take decisions that might improve city daily life. Aggregation of urban data according to multiple perspectives through the definition of proper indicators enables urban data exploration at different granularity levels for distinct categories of users. Furthermore, Semantic Web technologies may be used to enable interoperability and improve data access. In this paper, we propose a Smart Living Ontology, to provide a semantic-enriched representation of city indicators. On top of the ontology and users' characterisation, a Semantic Layer has been designed to enable personalised access to urban data.

Keywords: urban data exploration, semantic web, smart city ontology

1 Introduction

Smart City projects aim at driving local governments towards the strong use of technologies to support a higher quality of urban spaces and public services [1–3]. From an information viewpoint, different categories of users, including citizens, Public Administration (PA), utility and energy providers, must explore the large amounts of data from multiple, heterogeneous data sources, in order to take decisions that might improve city daily life. In recent research, Semantic Web technologies have been proposed to develop ontology-enabled applications, such as Smart Urban Cockpits and dashboards [8, 10], where proper indicators have been semantically described [6]. Indicators aggregate urban data according to several perspectives and provide a comprehensive view over underlying data without being overwhelmed by the data volume [7].

In this paper, we propose a semantics-enabled framework, which relies on the so-called Smart Living Ontology, to provide a semantic representation of Smart City indicators. The framework also includes the kinds of activities and users' categories for which indicators have been designed to share relevant information. A Semantic Layer, developed on top of the ontology, enables personalised exploration of urban data. The framework has been designed for decision makers, who need to have a view on heterogeneous urban data at different aggregation levels, ranging from energy consumption to garbage collection, pollution levels, citizens' safety. For example, the framework may allow building managers to monitor electrical consumption of administered buildings, by exploiting the indicators hierarchy in the ontology to distinguish electrical consumption according to different perspectives (e.g., consumption in common spaces, consumption of elevators), and to compare average values of consumption with other buildings at district or city level. Furthermore, the framework may enable citizens to make decisions about their activities by observing specific indicators (e.g., to avoid sport activities when pollution levels overtake tolerance thresholds).

This work was performed in the context of the Brescia Smart Living (BSL) Italian project[1], which promotes a holistic view of the city, where different types of data are explored to provide new services to both citizens and PA. The framework has been already presented in [5], where more details about the Smart Living Ontology and the implementation have been described.

This paper is organised as follows: in Section 2 we highlight the cutting-edge features of our approach compared to the literature; in Section 3, motivations are presented; Section 4 presents the Smart Living Ontology; Section 5 describes the Semantic Layer of the framework; in Section 6 we discuss implementation details and preliminary validation; finally, Section 7 closes the paper.

2 Related Work

In literature, the adoption of ontologies in Smart City projects targets *energy management*, where diagnostic models are built to discover energetic losses [11] or to perform optimisation for cost saving [3]; *facility discovery*, to search for city facilities and services [2]; *events monitoring and management* [1]; *Ontology-Based Data Access* (please refer to [12] for a survey and related flagship research projects), to cope with heterogeneous data sources inside the Smart City [4].

With respect to an OBDA perspective, our objective is to focus on data exploration by exploiting a semantic characterisation of Smart City indicators, also considering users' category and activities for which indicators have been

[1] `http://www.bresciasmartliving.eu`

designed. The semantic modelling we pursue also reinforces the characteristics of the BSL project, that if compared to other Smart City projects [1–3] provides a wider spectrum of urban data. Approaches focused on Ontology-Based Data Warehouses (OBDW) store analytical data, indicators, requirements and their semantics [10] or provide a semantic description of metrics used to compute indicators [6], in order to enable meaningful comparison among different aggregated measures. Differently from the aforementioned solutions, our approach is focused on the exploitation of indicators hierarchies and dimensional modelling to guide exploration of aggregated data for multiple categories of users, introducing a semantic relationship between users' profiles and indicators to foster personalised urban data exploration.

3 Motivating scenario

As a motivating example, let's consider John, the manager of several buildings located in different districts of the Smart City. John monitors the electrical consumption of the buildings, in order to implement energy saving policies (e.g., introducing LED lamps in common areas or planning renovation work to increase the energy efficiency class of buildings). Challenging issues are related to the capability of enabling John to fruitfully exploit available information. In this paper, we address such issues as follows.

Semantic specification of city indicators. Indicators are commonly defined to aggregate data according to several dimensions, for different categories of users (e.g., consumption-based indicator of electrical energy use). In our framework, the Smart Living Ontology is defined to provide semantic specification of the indicators, that takes into account indicators scope, in terms of spatial and temporal constraints, their hierarchical organisation and target users.

Personalised data exploration. Given the variety of urban data that can be explored, the selection of proper indicators is personalised taking into account users' profiles, composed of user's category, activities and preferential indicators.

Indicators recommendation to support decision making. Indicators recommendation is provided in order to help users to take decisions in their daily life. For example, John is provided with suggestions about indicators on electrical consumption of the administered buildings. To this aim, indicators scope and hierarchy, as well as filtering based on activities for which the indicators have been designed, are exploited to better focus the exploration.

4 The Smart Living Ontology

Figure 1 reports the main concepts and relationships of the Smart Living Ontology (SLO[2]). In order to face the heterogeneity and complexity of the Smart City

[2] The TBox of the ontology can be found at `https://tinyurl.com/onto-schema` (a free Web Protégé account is required)

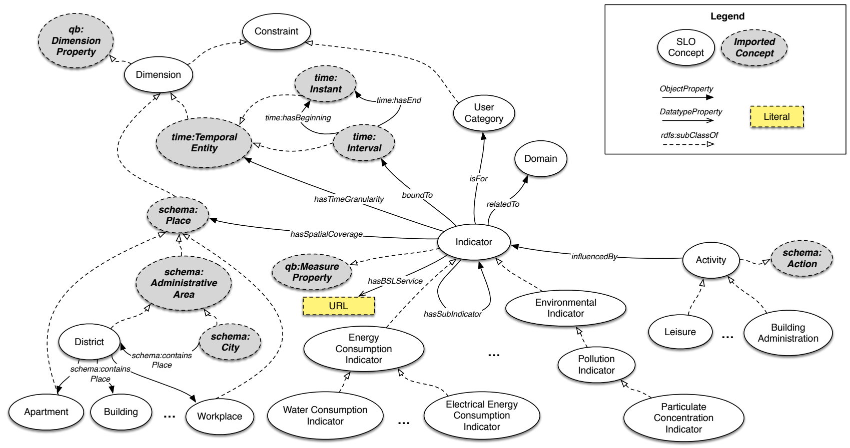

Fig. 1. A portion of the Smart Living Ontology (SLO).

domain, we rely on some foundation ontologies to cover a set of required pivotal concepts: (i) a geospatial mapping of the main structures of the city (e.g., buildings, streets, areas) and their topology; (ii) temporal entities; (iii) other high level concepts, that have been specialised to define the hierarchy of indicators and activities.
Indicators are specified as individuals of the `Indicator` concept or one of its sub-concepts in the indicators hierarchy. An indicator is further `relatedTo` a set of domain individuals (e.g., environment, safety, energy, mobility) to define the indicator scope, and a set of constraints. As shown in Figure 1, in the SLO a constraint can be either a dimension (time and space) or a user's category (e.g., building manager). Specifically, an indicator can be `boundTo` a time interval (e.g., values of electrical consumption available for the year 2017), may have a time granularity (`hasTimeGranularity` relationship), may be defined at city, street, district or more specific levels, such as buildings (`hasSpatialCoverage` relationship). Finally, knowledge about an indicator can be useful to perform specific activities, defined as individuals of the concept `Activity` or its sub-concepts (`influencedBy` property). An indicator is linked to a web-based service of the BSL Platform (`hasBSLService` property) to display the indicator values on the Smart City Dashboard, as explained in Section 6.

BSL users are profiled according to their category, their activities, the types of indicators explored by the user through the interactions with the framework. In the next section we detail how personalised exploration of indicators is performed based on the SLO, with the help of the motivating example.

5 Semantic Layer for Personalised Data Exploration

Personalised data exploration for each user can be achieved by effectively exploiting city indicators, properly selected according to the indicators domains, constraints and profiles of users. Figure 2 reports the steps for semantics-enabled data exploration and the I/O for each step.

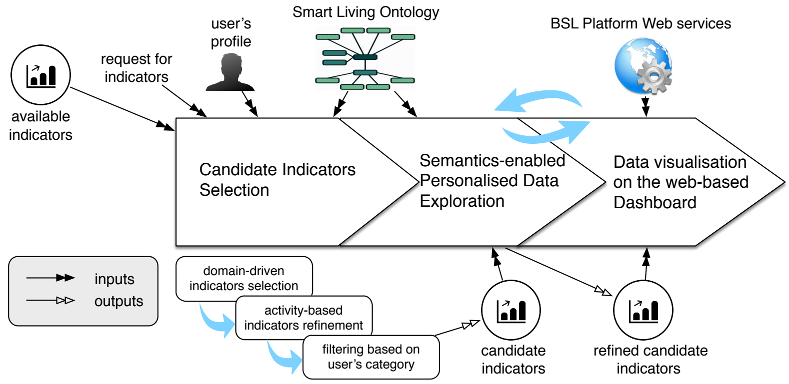

Fig. 2. The steps of semantics-enabled data exploration.

For example, let's consider again the user John in the motivating example, who is the manager of three buildings (namely `Building 1`, `Building 2` and `Building 3`) located in two districts of the city. Since John is usually interested in monitoring buildings, during the registration to the BSL platform, he specifies the activity `Monitoring` in his profile, jointly with his administered buildings, associating them to the districts they are located in.

Candidate indicators selection. In order to have an insight on the status of the buildings, for instance to evaluate whether replacing standard lamps with less energy-demanding LED ones, John issues a request to the framework. To support John in the request formulation, without requiring a detailed knowledge of ontology concepts and individuals, the framework enables him to specify a set of keywords K_r = {`energy`, `consumption`}, processed according to techniques aimed to match the keywords with ontology terms [9] (precisely, individuals of `Domain` and `Indicator` concepts or sub-concepts). The platform processes the request and returns, among the others, the indicator `NormalizedElectrical-EnergyConsumption (NEEC)`, which reports electrical consumption normalised with the number of apartments in the building. The indicator is selected because it is compliant with the keywords given in the request (domain-driven indicators selection), it is associated with the activity `Monitoring` in the ontology (activity-based indicators refinement) and it is compliant with the building manager category (filtering based on user's category). User's exploration history (in terms of formerly inspected indicators) is traced and it is taken into account during indicators suggestion, as it can be exploited to assess the degree of compliance between proposed indicators and user's past exploration preferences. Figure 3 reports the portion of the SLO containing the candidate indicators.

Semantics-enabled personalised data exploration. Starting from `NEEC` indicator (Figure 3), John can further explore other indicators being guided by the semantic relationships in the SLO. Exploration can be performed: (a) over the indicators hierarchy and/or (b) over the indicators dimensions. In the former, John selects the `NEEC` indicator and the framework suggests him more specific indicators (following the `hasSubIndicator` relationship). Exploration over the

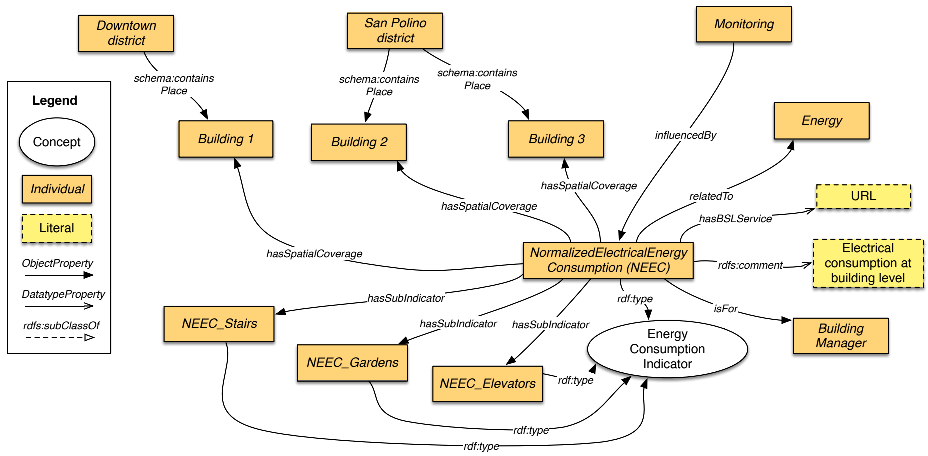

Fig. 3. Example of candidate indicator and related properties.

indicators dimensions exploits both the knowledge on the spatial coverage of indicators and the information stored in the user's profile. Starting from indicators previously selected for the John's building, the containment relationship that relates John's buildings with districts is exploited. Therefore, John could compare his buildings against others having similar characteristics or using different lighting solutions; this may stimulate John to consider the replacement of energy consuming light bulbs with modern LED lamps in shared spaces.

6 Implementation and Preliminary Validation

Figure 4 shows the web-based architecture of the semantics-enabled data exploration framework. The architecture is organised over three layers. Data on field, collected from domain-specific platforms through IoT technologies, as well as data from external sources (e.g., weather and pollution data), are loaded into the BSL platform (*BSL platform Layer*). Data is transferred to the BSL platform using RESTful services, SOAP-based services and MQTT Agents. Data is aggregated into smart city indicators, which are semantically specified in the *Semantic Layer*. The *User Access Layer* includes a web-based Smart City Dashboard to be used by citizens, PA and other users to explore data and take decisions (see [5] for more details). Using the web browser, users can register themselves and update their profile. The framework is implemented in Java and deployed under the Apache TomEE application server. The Smart Living Ontology is deployed in OWL using the Stardog[3] Triplestore. The Stardog module supports domain experts to maintain the ontology (concepts, relations and individuals), interacting with the web-based administration console provided by the module.

Preliminary experiments on the proposed framework, aimed at demonstrating its effectiveness in supporting candidate indicators selection, have been conducted considering a SLO composed of 57 concepts (among them, 30 indicators), 104 individuals, 207 object and datatype properties.

[3] https://www.stardog.com/

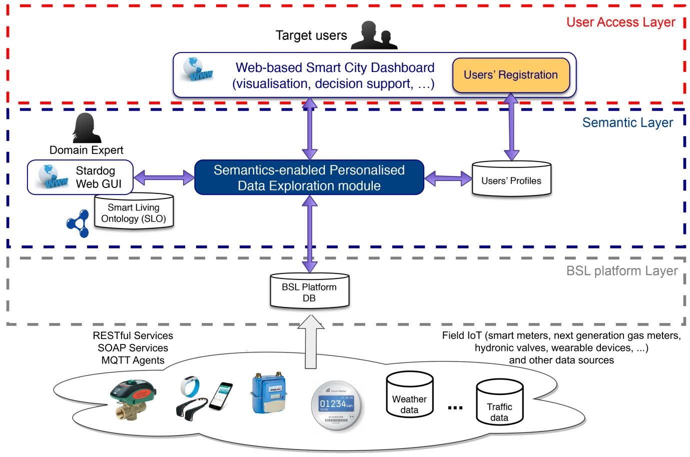

Fig. 4. Web-based architecture of the semantics-enabled data exploration framework.

We considered two kinds of requests: (A) requests where the user specified a set of keywords K_r in order to identify desired domains and indicators, and the user's profile does not contain any activity or preferential indicator; (B) requests where the user presents a richer profile (containing category, activities and preferential indicators), but specifies keywords in K_r, that only correspond to individuals of the `Domain` concept. We compared our ontology-based approach against a keyword-based search, where semantic disambiguation techniques have been applied to K_r [9], but SLO semantic relationships have not been exploited. Average precision and recall values for the keyword-based search are equal to 0.49 and 0.97 for type A (0.33 and 0.27 for type B, resp.), whereas for the ontology-based search they are equal to 0.99 and 0.98 for type A (0.94 and 0.93 for type B, resp.). Candidate indicators selection average execution time for type A is about 2559 ms, whereas for type B is about 1325 ms. Since both the compared approaches use keywords disambiguation techniques and the same keywords have been used during tests, difference in average precision and recall is due to the knowledge structure in the ontology. Usability tests are being performed to check the capability of the framework in facilitating user's access to urban data through the suggestion of candidate indicators. To perform usability tests, we considered metrics such as the number of exploration steps needed to obtain desired data, number of fails, number of successful explorations. Currently, the framework is being tested, with satisfaction, by a sample of users in two districts, a modern one, where new generation smart meters have been installed, and a district in city downtown, more densely populated and presenting older buildings. Usability experiments are being carried on within the Brescia Smart Living project until September 2019.

7 Conclusions

In this paper, we described a semantics-enabled framework composed of: (i) a so-called Smart Living Ontology, apt to provide a flexible representation of Smart City indicators; (ii) a Semantic Layer, to enable personalised exploration of urban data for different categories of users. The framework has been already presented in [5], where more details about the Smart Living Ontology and the implementation have been described. Ontologies represent knowledge structure that can be used to facilitate urban data exploration at different granularity levels and according to different exploration perspectives. Future effort will be devoted to extend the set of semantic relationships in the SLO as follows: (a) further relationships between indicators will be identified (e.g., to assert that two or more environmental indicators must be jointly monitored due to their harmful impact on the ecosystem); (b) strategies to dispense useful recommendations for promoting the users' virtuous behaviours, providing advice for healthy activities that should be practised by users.

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