A GIS-based Ontology for Representing the Surrounding Environment of Buildings to Support Building Renovation

Maryam Daneshfar, Timo Hartmann, Jochen Rabe

Technical University of Berlin, Berlin, Germany
maryam.daneshfar@tu-berlin.de

Abstract. This research focuses on developing an ontology for representing knowledge about the surrounding environment of a building in an urban context, considering the geospatial objects and processes such as built environment, vegetation, population and so on. The ontology can be useful to create a knowledge management system for different experts involved in the process of the building renovation, to extend the information and stretch the domain from the individual building to the environment. Knowledge about what entities and attributes to select is captured based on literature and investigating the pilot demonstration sites. Such an ontology can help to structure the surrounding data to support processes in different stages of the renovation. The final goal is to support planners in decision making process namely in site planning and pre-data collection phase, energy modeling, comfort analysis and so on to control cost and quality. Moreover, it can be valuable in further studies of integrating data of various sources for construction purposes.

Keywords: Ontology, Surrounding environment, residential building renovation.

1 Introduction

A rapid transition of urban areas towards energy efficiency is required mainly because of the challenges that climate change creates [1]. Geospatial solutions and strategies for energy monitoring management are needed to increase renewable energy usage in urban areas. Core geographical data, thematic maps of environmental data and administrative data such as planning regulations are required to depict the building's environment. Energy-efficient building renovation is an inter-disciplinary task that covers domains with different ontological outsets [2]. This research focuses on developing an ontology for the surrounding environment in the building renovation process. The intention is to provide a schema for surrounding data to extend the information and stretch the domain from the individual building to its surrounding environment.

The focus in the building renovation process is usually on the individual building and all the data collected are directly connected to the building or within a small radius of the building. Geospatial science, on the other hand, focuses on all phenomena which happen within a context connected to a specific location. Objects with specific locations and attributes are spatially related to each other. Based on Tobler's first law of geography, "everything is related to everything else, but near things are more related than distant things" [3]. Spatial processes, such as autocorrelation and interpolation can provide valuable information about every individual object in the context [3]. Some studies address the significance of geospatial data in different construction projects [4], but their focus is on the implementation of BIM[1] and GIS[2] data integration as two main sources of data for construction and geospatial domains. Göcer et al. [5] focus on BIM GIS integration for building refurbishment. Aghniaey et al. [6] describe how the weather data and shading of surrounding buildings affect the thermal comfort analysis of the buildings. Nevertheless, to the best of our knowledge, there is no comprehensive study to conceptually define what kind of geospatial data are required for the renovation workflow.

Ontologies as formal knowledge modeling, define a hierarchical classification of concepts and their interrelations [7]. Ontology is an approach for "an explicit specification of a conceptualization", and conceptualization is the way of "thinking about a domain" [8]. This paper aims to present an ontology that focuses on the surrounding environment of a building. The geospatial domain is a broad field. How we are observing it in the building renovation process delineates the concepts and attributes required in such an ontology. The goal of this ontology is to support planners for decision making in the site planning and pre-data collection phase to control cost and quality. Moreover, the surrounding environment is essential in other stages of the renovation process, for instance in energy modeling and performance assessment of the renovation design.

The paper is structured as follows: Section 2 presents the motivating scenarios for this research. Section 3 describes the spatial model and how urban GIS ontology is developed. Section 4 summarizes the methodology implemented for ontology specification and knowledge capture and the ontology implementation for the surrounding environment. Finally, the discussion and conclusions are followed in Sections 5 and 6, respectively.

2 Motivating Scenario

The residential building renovation process in cities is happening in the urban context and gets affected by all urban characteristics and processes in most stages of the renovation workflow. Some studies address the effect of the surrounding environment in the planning phase of the data collection. The surrounding buildings and vegetation characteristics of the environment, as well as other spatial objects such as parking lots, can affect the quality of the 3D scanning of the building [5].

In the detailed design phase of a renovation project, environmental data can directly affect the energy modeling of the building by integrating weather data coming from

[1] Building Information Modeling

[2] Geographic Information Systems

weather stations instead of using single sensors in the buildings which is more costly [9, 10]. Solar masks of the building and shade effect by considering 3D geometrical data of the surrounding buildings is another parameter in this phase.

Energy consumption in the urban context is affected not only by urban structure and building use but also by the socio-economic profile of inhabitants [11]. Therefore, the societal GIS data can be beneficial in this context as well. Different studies [12, 13] address the effect of built environment, roads, walkway, playgrounds, running water and pools in the acoustic comfort of the building. Air quality, outdoor temperature, wind speed and direction, and many other environmental factors can affect the comfort analysis of the building. Building's height to road's width ratio is used as an indicator to find the density of the urban area. Dense areas (with a high value of this ratio) can weaken approaching wind which reduces the air dispersion capability that leads to less indoor air comfort [14]. Accessibility to renewable energy sources and potential, energy, water, and smart grid network are all important in the phase of performance assessment of the renovation design.

Despite all this, the geospatial domain and surrounding environment data have received less attention specifically in the building renovation projects. Developing an ontology for the surrounding environment in the building renovation process helps to find out not only which knowledge system for the surrounding data can be considered to amend the renovation process, but also, to envisage the possibility of integrating the surrounding data with detailed individual building data. This can lead to a digital twin that replicates the real-world into a system that models it as genuine as possible.

3 Spatial Models

This section aims at establishing an understanding of geospatial ontology development and capturing knowledge in the geographical domain connected to the building renovation. The important characteristic of geospatial data is that it ties attributes to a location on the surface of the earth. The real-world is a very broad topic, and modeling and creating an ontology for such a system is a huge task. To this aim, this section is added in order to clarify how models and ontology are developed in this domain.

There are specific issues in developing an ontology for GIS because of the complexity, richness, and difficulty in the representation of geographical data [15]. The geospatial domain tries to model the real world in order to simplify it for specific applications [16]. Considering the real world as a physical model, how humans' perception is, creates the cognitive model. Expressing human's perception in a logical way in order to move toward a computer-understandable approach leads to a logical model. The logical model is categorized into two levels namely high-level and low-level (Figure 1). The high-level modeling considers the general concepts of space, while the low-level modeling focuses on specific concepts that belong to a particular domain and task [17].

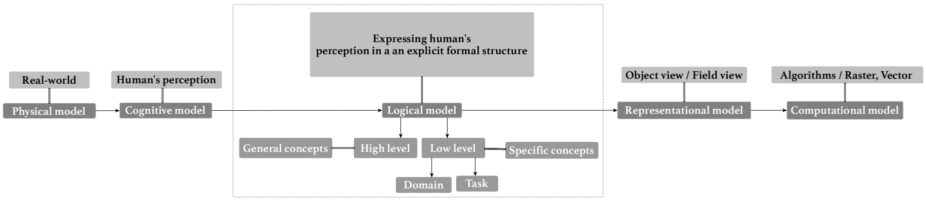

Fig. 1. A paradigm for geographic world

The concepts defined in the logical model will be represented in the representational model, which categorizes reality in two basic categories namely object view and field view [18]. Geographic objects are identified by their dimensionality. A point is a feature with 0-dimension, a polyline is a feature with 1-dimension, a polygon/surface is a feature with 2-dimensions, and a solid is a feature with 3-dimensions [19]. An object view can be utilized to represent features such as building blocks and roads. A field view, on the other hand, can represent the variation of specific phenomena such as elevation and slope. The model which digitalizes the representational model is called the computational model.

3.1 Ontologies in Urban GIS

This ontology focuses on the low-level logical model to target the concepts which are in the urban GIS domain and applicable in the building renovation task. This logical model can be used in future studies to represent the surrounding environment of the building. Semantic mediators can be used to bring the logical model into the representational model and consequently into a digitalized model.

Based on [19], ontologies in urban GIS comprises of objects, such as buildings and roads; processes, such as traffic flow and noise pollution; relations, such as buildings belong to building blocks; events, such as traffic accidents (Figure 2). This approach is used as a basis for developing an ontology for the surrounding environment in the building renovation process.

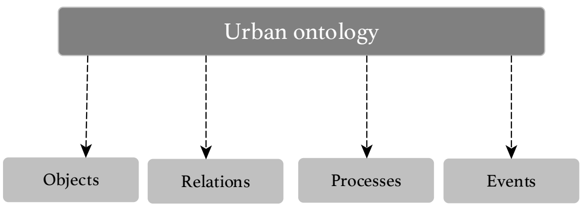

Fig. 2. Urban GIS ontology components

4 Research Approach

Based on the research gap described in the motivating scenario section, the principal objective of this study is to develop an ontology to aid experts in the renovation projects to gain knowledge on possibility of utilizing geospatial surrounding data. The research approach is the methodology which is used by France-Menah et al. [20] and includes ontology specification, knowledge acquisition, conceptualization and implementation and validation. Ontology specification is done by answering questions regarding purpose, scope, intended end users, intended use of the ontology which can be conceptualized in next steps.

What is the purpose? This ontology is developed to represent concepts related to the surrounding environment of a building to support experts in different stages of building renovation projects.

What is the scope? This ontology includes real-world objects such as building and road, as well as population-related, environment-related and energy-related processes and their relations.

What is the intended end-user? The intended end users are site planners, data collectors, energy experts and decision-makers who are involved in performance assessment of the renovation process.

What is the intended use? The ontology in intended to be used as a knowledge management system to give a comprehensive view of all the objects and data layers which are available in the surrounding of a building.

Some of the use cases which are developed according to literature, brainstorming and experts' opinions include site planning, building energy modeling, acoustic, air quality, thermal and lighting comfort analysis. Site planning is mainly referred to all the decisions made prior to the building data collection. 3D data collection of the individual building which is under renovation is a time consuming and costly task. Different methods are available for this task each of which requires its specific circumstances. Knowing in advance about the context where the building is located in, helps to select the method for the data collection. For instance, assuming that, the building is located in a high dense built area, or the façade is covered by single trees, or considering the culture of the population living in the vicinity may convey that drone-based data collection is not a good method for one specific site, and other alternatives such as terrestrial data collection is more practical.

Energy modeling occurs during the renovation design stage of the renovation workflow. One of the key parameters in energy modeling is external weather data. Historical and statistical weather data provided for energy modeling softwares are usually old datasets. Using weather data services which provide more recent data can help to get a more realistic model for the energy demand of the building. On the other hand, the weather data is usually measured in rural stations. Urban context, because of the urban heat island, experiences different weather situation from that received in the rural station. So, another benefit of having information about the urban context is to quantify urban heat island which results to urban weather and to calculate a more realistic energy model for the building.

The knowledge about the use cases and the data required for them is captured based on literature which implicitly accounts for surrounding data as an effective factor. Moreover, investigating the surrounding environment of pilot demonstration sites via aerial imagery, available maps and visiting the sites was another source of knowledge. Some sources in literature on knowledge capture are summarized in Table 1. When the ontology requirements are specified, next step is to formalize and conceptualize this specification. To this aim, a list of entities (objects) in a hierarchical order are defined along with their attributes and their relations to the processes.

Table 1. Use cases and sources for ontology knowledge capturing.

Use case	Surrounding environment data	Source
Site planning	Building block, road, railway, vegetated area, single tres, parking lot, monument, societal data …	Göcer et al. 2016
Building energy modeling (BEM)	Weather data (*.epw weather file for energy modeling in EnergyPlus)	Crawley 1998 Huang 2011
Acoustic comfort analysis	Road, walkway, railway, railway station, airport location, playground and park, running water, pool, lake, noise map	Herranz-Pascual et al. 2017 Kang et al. 2016
Air quality comfort analysis	Road, building , CO_2 emission map	Leung 2015, Li et al. 2009
Thermal comfort analysis	Weather data, building, single tree, energy consumption behavior of the occupants, re-newable energy sources	Aghniaey et al. 2018 Humphreys et al. 2000
Lighting comfort analysis	Building, tree	Jung 2018 [24]

4.1 Ontology for Surrounding Environment

A sophistication in defining urban GIS ontology is the concept of bona fide objects which address the visible objects in the landscape that are concrete in terms of physical boundaries and fiat objects which are not visible and do not have a physical border [21]. This ontology tries to cover all the physical (bona fide) objects in the surrounding environment in the context of building renovation projects such as building, as well as non-physical (fiat) objects such as district. The ontology also covers processes that convey information about the distribution of specific phenomena in a location. Both objects and processes are associated with some attributes and properties.

As shown in Figure 3, objects are categorized conceptually to the built area, vegetation, water, energy network, and traffic network. Each of the categories contains different data layers which have different attributes and properties. A district is a built area comprises of parcels, building blocks, buildings, parking lots and monuments. A district has *Area* and *Name* attributes, a parcel has *Area* attribute as well as *LanduseType.* Residential and commercial are examples of land use. A building block contains buildings that have attributes such as *Area*, *Height*, *FacadeMaterial*, *NumberofFloors.* A monument can have *ConstructionRegulation* constraint*,* for the buildings in its surrounding which may include the buildings under renovation project.

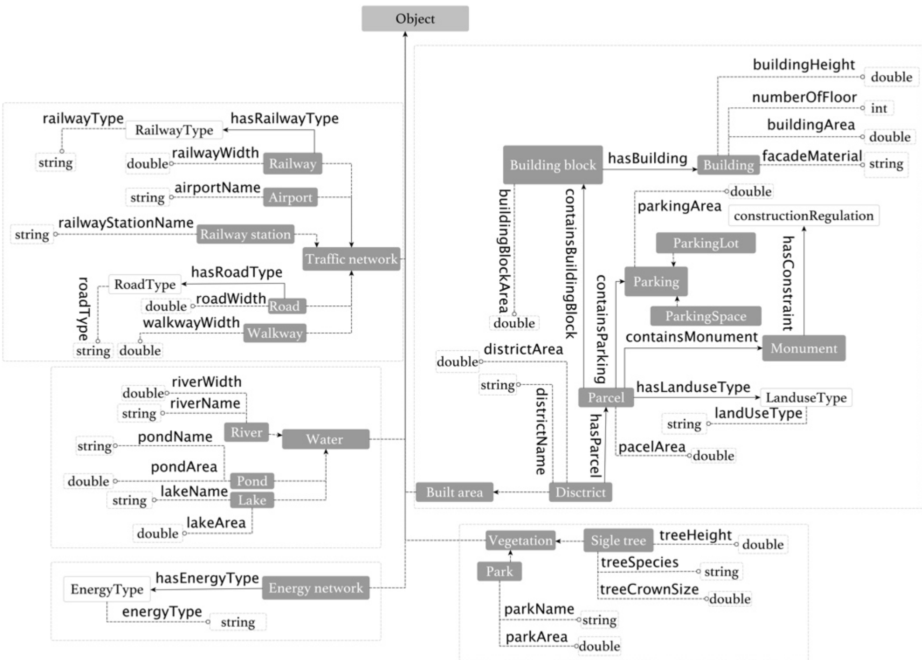

Fig. 3. Object categorization in the surrounding environment of a building

Vegetation category contains park with *Area* and *Name* attribute and tree with *Height*, *CrownSize* and *TreeSpecies* attributes. The energy network has *Type* attribute to distinguish between different energy types such as gas and district heating. Water category contains river, pond and lake with attributes such as *Name*, *Width*, *Area*. Traffic network category comprises road, walkway, and railway with *Width* and *Type* attributes. Additionally, it includes airport and railway station with *Name* and *Type* attributes.

On the other hand, as shown in Figure 4 and Figure 5, processes are also categorized conceptually in a similar fashion as objects. The main processes which can be helpful in renovation projects are population-related, energy-related and environment-related. The energy-related process components are energy consumption and renewable energy potential. The energy consumption process has *Type* to categorize the sort of the energy consumption and has *Value* to define the amount of consumption for each type. The renewable energy potential process is categorized to biomass, geothermal, wind power and solar energy potential. The amount of biomass potential in heat and electricity generation is defined by *Value*. The geothermal potential has *Depth* which is the depth of the drilling points to extract the energy and has *Value* to indicate the withdrawal performance. Wind power has *ElectricityFeed* that defines the amount of wind power potential. Solar energy potential is categorized into solar thermal and photovoltaic and determine the amount of heat and electricity feed with heat and electricity Value.

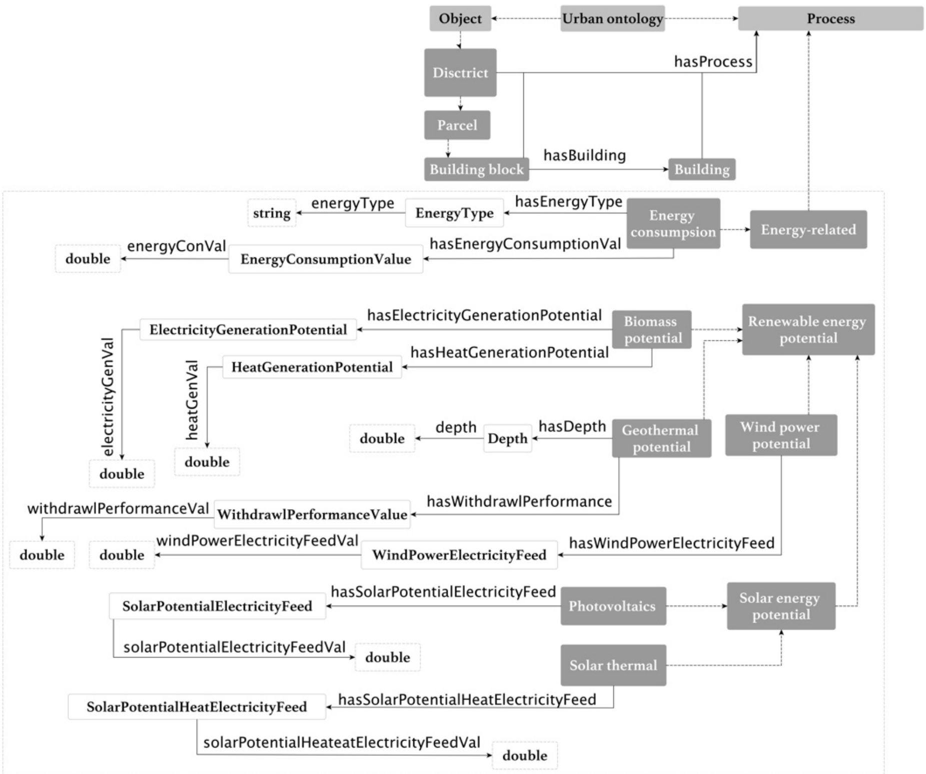

Fig. 4. Energy-related processes in the surrounding environment

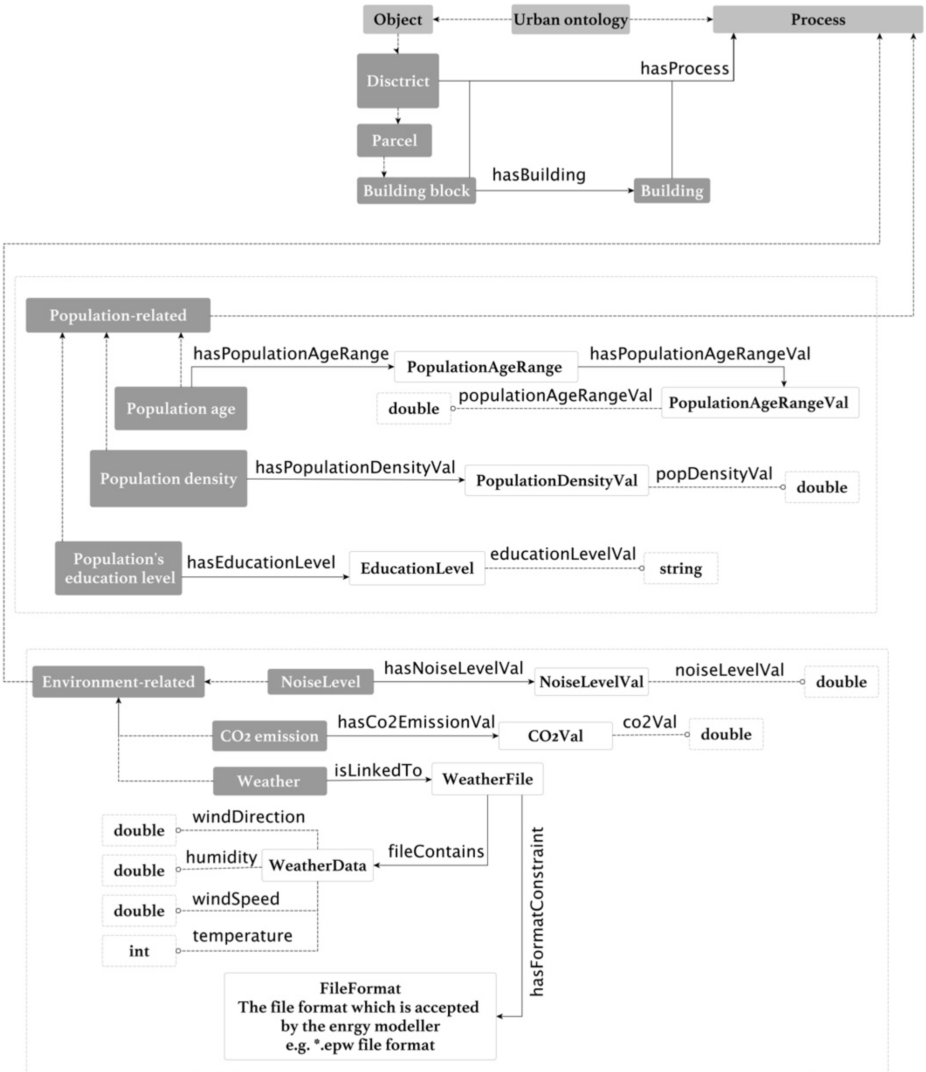

Fig. 5. Population-related and environment-related processes in the surrounding environment

The population-related category contains processes such as population age, density, and education level. Population age has *PopulationAgeRange* to classify the population age in different ranges and has *Value* to determine the share of each range. Population density has *Value* to define the amount of density, and population education level has *EducationLevel* to classify the population education in different categories and has a *Value* to define the share of each category.

The environment-related category contains noise level and CO_2 emission subcategories that are defined by a *Value*. Moreover, it comprises weather sub-category which is linked to *WeatherFile*. The weather file has a constraint of *FileFormat* that can be changing according to the energy modeling software (for instance *.epw file format for EnergyPlus software). District, building block and building can all have relation with the processes, meaning that information about all these processes may be available for each of these levels.

Representing this model in RDF/OWL standards is the best practice for storing vocabularies and ontologies and publishing them on web and making the ontology unique and available via URI. To this aim, the OWL of this ontology has been published and is available[3].

5 Discussion

Although many articles are focused on how to integrate BIM and GIS data semantically and practically, none of them address a comprehensive overview of what are the surrounding GIS data, which can be utilized in general in an AEC project and in particular in the building renovation process. Some studies have already mentioned the usage of surrounding data in some of the phases of the building renovation process, but there is a lack of attention in many other studies of renovation workflows. This topic is important because there are a lot of available geospatial sources of data which can help to generate more accurate results in the building renovation workflow. Hence, the first aim of this research is to provide this knowledge structure available for experts in the renovation process.

Based on use cases, brainstorming, and incorporating experts, this study focuses on developing an ontological representation of the GIS surrounding and environmental data to support planners, decision-makers, and experts involved in the renovation process. Increasing the number of interviews with experts who are both familiar with geospatial data characteristics and energy simulation can help to define new use cases where geospatial data are required in the renovation process.

Future activities include validation of the ontology to check the competency of the ontology towards addressing the problem identified in the motivating scenario. In this respect, a proof of concept of using this ontology for the renovation process will be presented. Moreover, this ontology is developed in a modular pattern. The upper levels in the ontology start with a conceptual element of built area, vegetation, and so on, the concepts which can be defined in an urban context. Using this modular format, it is also possible to connect this ontology with the existing and more wide-spread ontologies such as Building Topology Ontology (BOT). BOT contains the '*site*' component which based on its definition is about the site where for instance the residential building is located in [22]. The site element can be expanded to the surrounding environment where this ontology is defined in. On the other hand, as this ontology is developed on a conceptual level, details regarding the geometry for these objects are not included, although geometry is a relevant characteristic of all these objects.

---

3 http://dx.doi.org/10.14279/depositonce-10123

Hence, considering the integration of geometry description via Ontology for Managing Geometry (OMG) is considered as a future task [23].

With regard to the construction and geospatial domain, different open standards are developed e.g. IFC and CityGML both focusing on the 3D model of the building and built environment respectively. Investigating the possibility of using CityGML and other existing standards as the basis for developing the ontology developed in this research is considered as another future task.

Lastly, linked data is a concept related to interrelated datasets on the web, and it is considered as the heart of the semantic web. A future task would be investigating how developing this ontology and integrating it with other ontologies can contribute to the linked data.

6 Conclusion

In spite of the fact that buildings in urban areas are located in the urban context, got affected by those features and affect their surrounding during the renovation process, geospatial domain has not got enough attention. This research provides a knowledge system for the experts involved in the renovation workflow to bring into account those datasets for site planning, energy modeling and finding best design scenarios.

This study is a work in progress, investigating how this ontology can be evolved using other standards or incorporating components of other standards, also involving other experts to define new use cases or investigating possibilities of using other geospatial datasets in the already-mentioned use cases can be reflected in future development.

Acknowledgement

This research project is funded under the European Union's program H2020-NMBP-EEB-2018, under Grant Agreement no 820553.

References

1. Nowacka A, Remondino F (2018) Geospatial data for energy efficiency and low carbon cities – overview, experiences and new perspectives. ISPRS - International Archives of the Photogrammetry, Remote Sensing and Spatial Information Sciences, XLII-4, 467–474. doi:10.5194/isprs-archives-xlii-4-467-2018
2. Kamari, A., Corrao, R., & Kirkegaard, P. H. (2017). Sustainability focused decision-making in building renovation. International Journal of Sustainable Built Environment, 6(2), 330–350. doi:10.1016/j.ijsbe.2017.05.001
3. Miller H-J (2004) Tobler's first law and spatial analysis. Annals of the Association of American Geographers, 94(2), 284-289.

4. Song Y, Wang X, Tan Y, Wu P, Sutrisna M, Cheng J, Hampson K (2017) Trends and Opportunities of BIM-GIS Integration in the Architecture, Engineering and Construction Industry: A Review from a Spatio-Temporal Statistical Perspective. ISPRS International Journal of Geo-Information, 6(12), 397. doi:10.3390/ijgi6120397
5. Göçer Ö, Hua Y, & Göçer K (2016). A BIM-GIS integrated pre-retrofit model for building data mapping. Building Simulation, 9(5), 513–527. doi:10.1007/s12273-016-0293-4
6. Aghniaey, S., Lawrence, T. M., Mohammadpour, J., Song, W., Watson, R. T., & Boudreau, M. C. (2018). Optimizing thermal comfort considerations with electrical demand response program implementation. Building Services Engineering Research and Technology, 39(2), 219–231. doi:10.1177/0143624417752645
7. Li Song, Tian (2019) An Ontology-driven Cyberinfrastructure for Intelligent Spatiotemporal Question Answering and Open Knowledge Discovery. ISPRS International Journal of Geo-Information, 8(11), 496. doi:10.3390/ijgi8110496
8. Gruber T-R (1995) Toward principles for the design of ontologies used for knowledge sharing? International Journal of Human-Computer Studies, 43(5-6), 907–928. doi:10.1006/ijhc.1995.1081
9. Crawley, D. B. (1998). Which weather data should you use for energy simulations of commercial buildings?. *Transactions-American society of heating refrigerating and air conditioning engineers*, *104*, 498-515.
10. Huang, Y. J. (2011). International Weather for Energy Calculations.
11. Bocher E, Petit G, Bernard J, Palominos S (2018). A geoprocessing framework to compute urban indicators: The MApUCE tools chain. Urban Climate, 24, 153–174. doi:10.1016/j.uclim.2018.01.008
12. Herranz-Pascual, K., García, I., Diez, I., Santander, A., & Aspuru, I. (2017). Analysis of Field Data to Describe the Effect of Context (Acoustic and Non-Acoustic Factors) on Urban Soundscapes. Applied Sciences, 7(2), 173. doi:10.3390/app7020173
13. Kang, J., & Schulte-Fortkamp, B. (Eds.). (2018). Soundscape and the Built Environment. doi:10.1201/b19145
14. Li, X.-X., Liu, C.-H., & Leung, D. Y. C. (2009). Numerical investigation of pollutant transport characteristics inside deep urban street canyons. Atmospheric Environment, 43(15), 2410–2418. doi:10.1016/j.atmosenv.2009.02.022
15. Fonseca F-T, Egenhofer M-J (1999) Ontology-driven geographic information systems. Proceedings of the Seventh ACM International Symposium on Advances in Geographic Information Systems - GIS '99. doi:10.1145/320134.320137
16. Kottman C, Reed C (2009) The OpenGIS abstract specification topic 5: features. *Open Geospatial Consortium Inc*.
17. Leung, D. Y. C. (2015). Outdoor-indoor air pollution in urban environment: challenges and opportunity. Frontiers in Environmental Science, 2. doi:10.3389/fenvs.2014.00069
18. Fonseca F, Egenhofer M, Davis C, Câmara G (2002) Semantic granularity in ontology-driven geographic information systems. *Annals of mathematics and artificial intelligence*, *36*(1-2), 121-151.
19. Fonseca F, Egenhofer M, Davis C, Borges K A (2000) Ontologies and knowledge sharing in urban GIS. Computers, Environment and Urban Systems, 24(3), 251–272. doi:10.1016/s0198-9715(00)00004-1
20. France-Mensah, J., & O'Brien, W. J. (2019). A shared ontology for integrated highway planning. Advanced Engineering Informatics, 41, 100929. doi:10.1016/j.aei.2019.100929
21. Smith B (1995) On drawing lines on a map. In: Frank, A. U., Kuhn, W., eds. International Conference on Spatial Information Theory - A Theoretical Basis for GIS (COSIT 95), Sep 21-23 1995 Semmering, Austria. BERLIN 33: Springer-Verlag Berlin, 475-484

22. Building Topology Ontology (https://w3c-lbd-cg.github.io/bot/)
23. Wagner, A., Bonduel, M., Pauwels, P., & Uwe, R. (2019). Relating geometry descriptions to its derivatives on the web. In 2019 European Conference on Computing in Construction (pp. 304-313).
24. Jung, S., & Yoon, S. (2018). Study on the Prediction and Improvement of Indoor Natural Light and Outdoor Comfort in Apartment Complexes Using Daylight Factor and Physiologically Equivalent Temperature Indices. Energies, 11(7), 1872. doi:10.3390/en11071872